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RECOVERY OF PETROLEUM REFINERIES
CONTAMINATED BY FALLOUT

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ABSTRACT

The Office of Civil Defense, Department of Defense, is sponsoring a series of studies on the recovery of certain essential major industries in the U.S. from the effects of nuclear attack. Various agencies are developing recovery input data that will eventually be fed to automatic computers to prepare production programs, consistent with surviving resources, for meeting priority requirements during the first two years after attack.

The present study deals with the petroleum refinery industry. The case studied is that in which a given refinery is contaminated by radioactive fallout from one or more nuclear detonations occurring essentially simultaneously at some distance so that the refinery is not damaged by blast or fire. Before recovery of the plant can be started, entry into the plant area must be postponed until the radioactivity has decayed sufficiently so that excessive radiological doses will not be accumulated by recovery personnel. After entry. personnel must first decontaminate the vital areas of the plant, and then repair the equipment that has been damaged because of insufficient shutdown time. Estimates of the times and efforts required for recovery are made for a subgroup of 16 refineries that encompass all refinery sizes found in the industry; standard intensity* ranges of radioactive fallout from 300 r/hr to 30,000 r/hr are considered. Generalized empirical formulations of these estimates are developed for the subgroup and are applicable to all refineries in the industry. Estimates of the times for recovery can be calculated for various choices of the controlling parameters—length of work shift; standard intensity; size of refinery; etc.

Recommendations are made that would reduce the effects of such attacks on oil refineries and expedite their recovery.

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* The standard intensity of a radiation field is the value of the intensity in r/hr when extrapolated back to one hour after burst. The use of the standard intensity simplified the representation of the results and the calculations based on them.

The Problem

The Office of Civil Defense needs computer input data on the effort and time required to recover essential major industries in the U.S. after nuclear attack. Various agencies are developing recovery input data that will eventually be fed to automatic computers to prepare production programs consistent with surviving resources, for meeting priority requirements during the first two years after attack. The present study, one of a series to provide these data, has dealt with the recovery of petroleum refineries from contaminating nuclear attack. The situation considered is that in which a refinery is far enough from the points of the nuclear detonations that it is not damaged by airblast or fire but is close enough to be in the radioactive fallout area. The impending arrival of fallout necessitates personnel shutting down the plant because of potential radiation hazards and going to shelter or evacuating the plant and fallout area. Recovery of the plant to resume operations will require decontamination of the plant and also repair of plant damage caused by shutting down too fast in the emergency.

Findings

From analysis of general information on the almost 300 refineries in the U.S. and detailed information on a representative subgroup of 16 refineries, estimates have been derived of the following for various combinations of standard intensity, permissible recovery personnel dose, decontamination effectiveness, shutdown time, hours worked per day, and percent of production capacity achieved:

      1. Earliest permissible time of entry into the contaminated vital area of the refinery to start decontamination.

      2. Man-days and time in days required to decontaminate if necessary a staging area (from which recovery operations may be conducted) and to decontaminate the vital area.

      3. Man-days and time in days required to repair damage caused by fast emergency shutdown.

4. Total man-days for decontamination and repair, and time of availability, i.e., time to completion of repairs, when operations can be resumed.

The times of availability of resources are given by an empirical equation of the form:

$$T_A = A(d_o)^\alpha + B(S)^\beta$$

The first term gives the sum of the earliest entry time and the decontamination time; d_o is the standard intensity. The second term gives the time required to conduct the repairs; S is the size of the refinery in barrels per day of crude oil processed. The other parameters (A, α, β, B) depend on the length of the work shift, the effectiveness of decontamination, etc. Detailed instructions and examples of the calculations as well as tabulation of the parameters are presented in Section 5.

To give the reader an idea of the magnitude of the effort and time required for recovery, the estimates for an intermediate case as tabulated in Section 5 are presented here. For 100% recovery for the 1 hr shutdown case, the effort required for recovery ranges from 73 man days for a small refinery with low standard dose rate intensities to 116,000 man-days for a large refinery in a 30,000 r/hr field; the times of availability of resources range from 8 days to 170 days after the time of burst.

Recommendations

To alleviate the effects of radioactive fallout on petroleum refineries and to expedite their recovery, it is recommended that:

1. General survival plans be formulated for refineries that will include measures for personnel protection (shelters and evacuation).

2. Central groups or nuclei of personnel from the petroleum industry be trained to initiate and direct recovery operations.

3. Plant personnel, at least key personnel, be trained in the fundamentals of radioactive fallout phenomenology, radiation hazards, and radiological defense (countermeasures).

4. A study be made for a given refinery to determine the optimum procedure for fast shutdown to minimize damage and consequent repairs, and personnel be drilled in this procedure.

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5. A series of decontamination tests be made on surfaces in refineries and other industrial complexes to obtain more reliable data for planning and recovery purposes.

6. Vital-area surfaces be prepared for easier, quicker decontamination.

7. An investigation be made to determine more expeditious means of obtaining the critical equipment and materials that may be required for repairs.

8. Selective shutdown of refineries by size be made prior to the attack, at earliest warning, to minimize the damage from fast shutdown operations, and selective recovery of refineries by size be made to maximize the total recovery output for the effort expanded.

(These recommendations are discussed in detail in Section 7.)

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SECTION 1

INTRODUCTION

1.1 STATEMENT OF PROBLEM

The Office of Civil Defense (DOD) is sponsoring a series of studies on the recovery of certain essential major industries in the United States from the effects of nuclear attack. Various agencies are developing recovery input data that will eventually be fed to automatic computers to prepare production programs, consistent with surviving resources, for meeting priority requirements during the first 2 years after attack.

The present study, conducted by the U.S. Naval Radiological Defense Laboratory (NRDL), has dealt with the petroleum refinery industry. The situation studied is that in which a given refinery is contaminated by radioactive fallout from one or more nuclear detonations occurring essentially simultaneously but is distant enough not to be damaged by airblast or fire.* By agreement between OCD and NRDL, the range of standard radiation intensities (r/hr at 1 hr after burst) was specified as 100 r/hr to 30,000 r/hr,** and the radiation dose restrictions were specified as no more than 30 r/day, 230 r/2 weeks, or 1000 r/year.

1.2 OBJECTIVES

1. To obtain estimates of the effort and time that would be required to recover any petroleum refinery in the United States contaminated by radioactive fallout but not damaged by airblast or thermal effects.

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* Appendix A provides fundamental information on radiological defense. For further details, see Refs. 1, 2, and 3.

** Intensity of 30,000 r/hr outside the airblast and fire damage ranges could result only if the fallout in the area resulted from several detonations.

2. To recommend measures that could be taken to alleviate the effects of contaminating nuclear attack on refineries and also expedite their recovery.

1.3 BACKGROUND INFORMATION

1.3.1 Radiological Aspects

In the situation under consideration, radioactive fallout from one or more distant nuclear detonations is being transported by the winds toward the given refinery. Radioactive fallout emits penetrating gamma radiation that can be a serious biological hazard to unprotected personnel. Thus, before fallout arrives and contaminates the refinery, personnel must either take shelter or evacuate the refinery and also the surrounding potential fallout area to avoid receiving large radiation doses that could be incapacitating or lethal. Then, before personnel can leave shelter or return to the refinery to start decontamination operations, there may be a delay of days or weeks until the radiation intensity is reduced by radioactive decay to such a level that working personnel will not receive doses larger than the maximum doses specified in the problem. Decontamination* consists essentially of removing the deposited fallout from surfaces in the vital area of the refinery to some distant isolated location. The purpose of decontamination is to reduce the time of availability (i.e., time when production could be started) while keeping personnel doses within the specified dose restrictions. The vital area is that portion of the plant where the refining processes and main supporting functions are concentrated. The vital area requires almost continuous occupancy by personnel to carry out refining operations. Certain areas, such as the tank farm and storage areas, are not considered part of the vital area, since continuous occupancy by personnel is not necessary. It is desirable, therefore, to carefully select the vital area and its size so as to minimize the decontamination effort required.

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* In some publications that refer to radiological defense, the term "radiological reclamation" includes (1) decontamination, which is the removal of fallout contaminant from a surface by such methods as firehosing and mechanical or manual sweeping; and (2) surface removal, which is the removal of the fallout contaminant from surfaces, such as lawns and dirt roads, by bulldozing, scraping, etc. In this report, reclamation and decontamination are used interchangeably.

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1.3.2 Emergency Shutdown Aspects

A major factor in the situation under consideration is that, before taking shelter or evacuating, the personnel must first shut down the plant if it is to be recoverable. Abandoning the plant in panic would probably result in a total loss of the plant. Normally, it takes a significant amount of time to shut down a plant without damaging it; even a medium-sized plant may take as long as 48 hours. Shutdown involves the gradual dissipation of large amounts of energy in the form of high temperatures and high pressures in reaction vessels. In the emergency envisaged, the shutdown time may have to be sharply reduced to some time, say, between 1 hour and 6 hours. Rapid (or incomplete) shutdown will result in equipment damage. Very brief shutdown times-less than an hour--will result in unknown but considerable damage. In the event of hurried or uncontrolled shutdown, materials that were in a gaseous or liquid state in the processing will cool and solidify in the complex piping system, stills, and other equipment. If such materials are not removed, they may also corrode the equipment. Then, before repairs can be made, the replacement equipment, necessary materials, etc., must be available.

Hence, before production can be resumed, personnel will have to recover the refinery by decontaminating the vital area, making repairs, removing solidified material, and replacing some equipment.

Fires could start and cause serious damage. Because of the unpredicability of the extent of fires in general, they do not lend themselves to quantitative studies. As a consequence, they have not been considered in this study.

1.3.3 Recovery Time Sequence

The recovery of a particular refinery will involve the following three dose-time-dependent steps: (1) From burst time to earliest entry time. Once the fallout has deposited on the plant, entry to the area must be delayed to a time when the radioactivity has decayed sufficiently that the doses received by the recovery personnel are within the dose restrictions of the problem. (2) From earliest entry time to completion of radiological recovery of the vital area. (3) From the completion of radiological recovery, or the time of entry for repairs, to the completion of repairs. Although reclamation and repairs have been considered as separated in time in this analysis to simplify computations, they could be carried out concurrently to a certain extent. That is, repairs might be started in already decontaminated areas.

The sketch below illustrates the sequence of the three steps. The dose restrictions imposed on the problem control the earliest entry time

WAIT	DECONTAMINATION	REPAIRS

T_O T_E T_E+T_D T_A
$(T_E+T_D+T_R)$
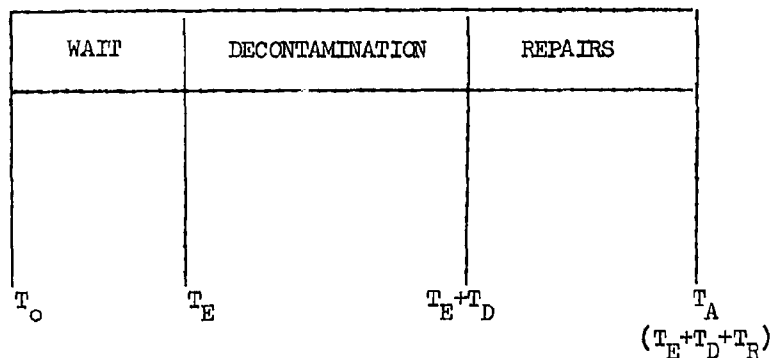
T_O =   time of detonation;

T_E =   earliest permissible entry time and beginning of decontamination;

T_E+T_D =   time at which decontamination is completed and repairs are started;

T_A =   repairs are completed and production is resumed (time of availability of resources)

for a given standard intensity. The time to decontaminate the vital area will depend on its size, the decontamination work schedule, and the method and rate of decontamination. The time for repairs will depend on the refinery size, the extent of damage, the work-force size, and the work schedule. Personnel doses must be computed separately for 1-day, 2-week, and 1-year occupancy following entry to see that they do not exceed the dose restrictions, singly or combined. If any of the restrictions are exceeded, a later entry time must be accepted.

In an actual situation, the permissible entry time would be delayed if recovery personnel were to receive significant doses because of inadequate protection during and after the fallout period, for example, while shutting down the plant, going to shelter, or evacuating

the fallout area. There would also be a delay after decontamination is completed and before repairs could be started if essential replacement equipment and repair materials were not available. In the present study, these delays were unpredictable and were therefore eliminated by simplifying assumptions.

1.4 APPROACH

1.4.1 General Approach

The approach to the problem solution consisted essentially of selecting a representative subgroup of refineries from the entire group of refineries in the U.S., making a detailed analysis of the recovery of the individual refineries in the subgroup, combining the individual results, and from the combined results obtaining estimates of the total man-days and total time in days (time of availability of resource) that would be required to recover any refinery in the group. The specific procedure followed is described below. In addition to the total estimates for specified and assumed conditions, an equation was developed for calculating the time of availability of a given refinery for any set of conditions.

1.4.2 Specific Procedure

The study was conducted in what may be considered three basic phases: a preliminary survey of the petroleum industry, preparation and sending of a questionnaire to subgroup refineries, and analysis of the questionnaire answers and other data.

1.4.2.1 Preliminary Survey. This survey was made to acquire basic information along with an understanding of the various aspects of the problem. The information was obtained by reviews of literature of the petroleum industry, personal contacts with several refineries in the West and the East, and an intensive inspection of a large Western refinery. The refineries contacted included two large refineries on the east coast and four large refineries on the west coast; the final version of the questionnaire was sent to nine additional California refineries.* A compilation of refinery characteristics that are of interest to the problem is included in Appendix B. On the basis of the information so obtained, it was possible to start developing the

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* Some of the refineries were unable to furnish complete data, and as a consequence in some of the graphs, there is an apparent inconsistency in the number of points shown.

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method of analysis. Because of insufficient knowledge of certain variable aspects of the situation considered, certain simplifying assumptions were necessary to make the problem solvable; these assumptions are listed and discussed in 1.5.1. It was also seen that, because of the time limitations of the study, it would not be possible to analyze the entire group of almost 300 refineries. Thus, a small representative subgroup of 16 refineries was selected for detailed, individual analysis. The selection was based on data in Ref. 4. The sizes and complexities of the subgroup encompass those of the entire group. Examination of the information brought out certain parameters that would be necessary for the solution to the problem and indicated the method of analysis that was finally developed.

1.4.2.2 Questionnaire. A questionnaire was prepared and sent to the 16 refineries in the subgroup. The questions were directed toward items on decontamination and emergency-shutdown repair needed for the analysis. Following is a list of the major items:

1. General description of the refinery, with map or aerial photograph.

2. Size and description of the total employee complement.

3. Description of the water supply and capacity, fire-fighting capabilities, drainage system and capacity, etc.

4. Utilities used in refinery process.

5. Damage effects of rapid emergency shutdown, along with pessimistic and optimistic estimates of the time and manpower that would be needed to make repairs to achieve partial or full production capacity.

6. Equipment, normally available for "housekeeping" tasks, that might be useful in decontamination work.

7. Barrels per day of the 3 main products manufactured.

The questionnaire answers were followed up with personal discussions with cognizant personnel in the refineries. A complete copy of the questionnaire is presented in Appendix C. The information obtained from the refineries is not presented in its original form in this report for two reasons. First, the report would have been unnecessarily bulky; second, many of the refineries contacted requested that their replies not be published and identified with them as they were "Company Confidential."

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1.4.2.3 _Analysis of Data._ As noted in 1.3.3, to derive recovery estimates for an industrial complex, such as a petroleum refinery, requires separate estimates for the 3 main chronological steps involved. For the first step, therefore, estimates were made of the earliest permissible times of entry of decontamination personnel into the contaminated plant area. These times are applicable to any refinery, since they are primarily dependent on the existing radiation intensity of the area, the dose restrictions, and the decontamination work schedule. For the second and third steps, however, detailed analyses were made of the individual subgroup refineries to obtain estimates of the following: Step 2: effort in man-days and time in days to decontaminate the vital area of the refinery; Step 3: effort in man-days and time in days to repair plant damage resulting from fast emergency shutdown. For the specified dose restrictions of 1.1, computations were made of accumulated doses for refinery personnel.

For each subgroup refinery analyzed and for each recovery step, computations were made of the desired relationships among the parameters, with the accumulated doses being kept within the dose restrictions. Then, for each step and each relationship, plots were made of the computed values and a determination was made of an average curve, or of upper and lower limit curves, depending on the nature of the relationship and the data. The analytical treatment for each step is briefly described as follows:

Step 1: Computations and plots were made of earliest entry time vs standard intensity for each of the dose restrictions and for decontamination work days of 4 hr and 8 hr, 7 days/week. (Details are given in Sec. 2.)

Step 2: From the basic data, plots were made of the total number of employees vs refinery size, and vital-area size vs refinery size. The straight-line curves on log-log graph paper indicated that the correlation was good and that the curves could be used for generalizing to all the refineries. Using these curves and decontamination-rate and logistics data, computations and plots were made of decontamination man-days vs refinery size, and decontamination time in days vs refinery size. (Details are given in Sec. 3.)

Step 3: The questionnaire answers on repairs were analyzed for each subgroup refinery. Then, the individual results were combined into composite plots of repair man-days vs refinery size, and repair time in days vs refinery size, required to achieve 10%, 30%, and 100% production capacity for 1-hr, 3-hr, and 6-hr emergency shutdown times. (Details are given in Sec. 4.)

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On the basis of the analyses described in Sections 2, 3, and 4, equations were derived for obtaining repair effort and time of availability of resource for any-sized refinery. (Details and results are given in Sec. 5.)

1.4.2.4 <u>Equations for General Solution</u>. As previously pointed out, the time of availability of resources for any refinery is the sum of 3 times: earliest entry time, decontamination time, and repair time. Analysis of the data revealed that the sum of the first 2 times depended primarily on the standard intensity. This sum, when plotted against the standard intensity, gave a straight line on log-log paper for each choice of work schedule considered. Plots of repair time <u>vs</u> refinery size also gave straight lines on log-log paper for the same work schedules. From these curves, general equations were derived that give effort and time as a function of the governing parameters. These equations express concisely these relationships and are suitable for machine computation. For illustration purposes, an intermediate case is presented in tabular form. (Section 5.)

1.5 LIMITATIONS OF RESULTS

Early in this study, it became apparent that the quality of the input data did not warrant a highly detailed and refined approach to the solution. A broad approach would reach the limits of attainable accuracy and would achieve this with less effort and time. The most obvious factors that limit the accurate determination of man-days required for recovery are the following:

1. Unavailability of complete technical data pertaining to many aspects of fallout phenomenology.

2. Inability to evaluate the effects of the psychological factors attendant on a chaotic situation following nuclear attack.

3. Unfamiliarity with decontamination after an actual fallout event, and the necessity to extrapolate data from controlled, small-scale experiments.

4. Inability to estimate accurately the effort required for repairs of plant equipment.

5. Assumptions that were necessary to make the problem solvable.

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The estimates for the times of recovery resulting from this analysis present a possible range of values. Other answers are possible for the calculated times than those given, depending on the choices one makes for the values of the controlling parameters. For example, when one considers the repair phase, the man-days required for repairs for a given shutdown time and a particular refinery will have but one answer; however, when one proceeds to calculate the times required to conduct the repairs, a unique answer cannot be obtained. The estimated times for repairs will depend on the size of the work force and on the hours worked per shift. Hence, the times for recovery calculated here are not the only possible solutions.

1.5.1 Simplifying Assumptions

To make the problem amenable to quantitative analysis and solution, the following simplifying assumptions were made:

1. Plant personnel do not panic but remain for a limited time to close down the plant before fallout arrival.

2. Plant personnel are well drilled in emergency shutdown.

3. The same personnel do the decontamination work, make the repairs,* and resume the plant operations.

4. Competent personnel are available to direct the recovery (decontamination and repair) operations.

5. Recovery personnel receive negligible doses before the earliest entry time.

6. During nonwork hours, recovery personnel are quartered at a staging area or shelter where they receive negligible doses or at some quarters outside the refinery so located that when they travel to and from the refinery they receive negligible doses.

7. Equipment, instruments, and supplies are available for carrying out decontamination.

8. Spare parts, units, equipment, supplies, etc. are available for making repairs.

9. The radiation field is not disturbed by weather.

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* Estimating the size of the repair work force is very speculative; if better estimates can be obtained than the ones here, other times of availability could be easily calculated.

10. Good weather prevails during the recovery operations.

The effort required to decontaminate and make repairs in the presence of rain, snow, or freezing temperatures would be considerably increased. Personnel from one refinery estimated that repairs conducted in bad weather would require about 1.5 times as many man-days as those conducted in good weather.

1.5.2 Pertinent Governing Parameters and Assigned Values

The determination of the total man-days and the times of availability depended on many parameters and their assigned values. The parameters and their values were either mutually agreed upon by OCD and NRDL or were selected after careful consideration of their applicability. The effect on the recovery schedules of varying certain parameter values was investigated. The parameters and their assigned values are as follows:

Standard intensity: 100, 300, 1000, 3000, 10,000, and 30,000 r/hr. These values are in the range specified in the problem (see 1.1).

Dose restrictions: No more than 30 r/day, 230 r/2 weeks, or 1000 r/yr, also as specified in the problem.

Radioactive decay rate: The rate used in Ref. 1.(Appendix D shows that use of any other commonly accepted rate would not have greatly changed availability times or recovery personnel accumulated doses.)

Decontamination residual numbers: The residual number, a measure of decontamination effectiveness, is defined here as the ratio of the intensity during or after decontamination to the intensity before decontamination.* In computing accumulated doses for the decontamination period, residual-number values of between 0.5 and 1.0 were assumed. It was assumed that decontamination would achieve a residual number of 0.1. (As noted in 1.5.1, it was assumed that recovery personnel receive negligible doses during nonwork hours.)

Decontamination methods: It was assumed that a once-over decontamination of the vital area, using appropriate methods for each surface, would produce the desired residual number of 0.1. If a lower residual number was required, repeated application of the methods to the respective surfaces would be necessary.

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*Sometimes referred to in this report as the free-field intensity. Dose accrued in undecontaminated areas is referred to as free-field dose.

Refinery size: Barrels per day of crude oil processing capacity (B/D); equivalent to barrels per stream day (BPSD).

Vital-area size: Size of area where the essential refinery processes and essential supporting activities are carried out and which require almost continuous occupancy by personnel. This area does not include such areas as the tank farms and storage areas which require only intermittent occupancy.

Recovery work force: Assumed to be 75% of the total number of refinery employees. The same work force performs decontamination, makes repairs, and resumes refinery operations.

Work schedule: For decontamination, two schedules are considered: 4 hr/day, 6 shifts/day, 7 days/wk; and 8 hr/day, 3 shifts/day, 7 days/wk. For repairs, 8 hr/day, 3 shifts/day, 7 days/wk. A man-day is considered equal to 24 man-hours.

Emergency shutdown time: 1 hr, 3 hr, and 6 hr.

Percent production capacity achieved: 10%, 30%, and 100%. Percent production capacity is defined as the ratio of the production capacity in barrels of crude processed per day to the normal (100%) production capacity times 100.

1.6 PREVIEW OF REPORT

This report is composed of seven sections and six appendices. The next section, Section 2, considers the earliest entry times at which recovery can begin, gives an illustrative example to show how earliest entry times are determined, tabulates earliest entry times for various values of the parameters, and investigates the sensitivity to changes in controlling parameters. Section 3 considers the decontamination phase of the recovery, selection of the area to be decontaminated, rates, logistics, manpower, and times required. Section 4 considers the repair phase of the recovery, and presents the man-days and times required for repairs of refinery equipment damaged by the emergency shutdown time based on estimates made by refinery personnel in answer to the questionnaire. Section 5 is primarily directed to generalizing the results of the analysis and formulating these results in terms of empirical equations that are suitable for machine computation. In particular, such formulation is given for the repair entry times and the repair times; the time of availability of resources is then obtained by summing these two times. Illustrative examples are included to demonstrate the method of calculation. Section 6 is included to show

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that, in the recovery plans developed, the accumulated doses do not exceed the dose restrictions. Section 7 lists certain recommendations that would aid in reducing the effect of a nuclear fallout attack and expedite the recovery.

Appendix A explains some of the fundamental aspects of ionizing radiations and of radiological defense pertinent to this study and is primarily directed to readers unfamiliar with these subjects. Appendix B describes the characteristics of refineries that are pertinent to their decontamination and shutdown operations. Appendix C contains a copy of the questionnaire that was sent to each of the refineries in the sample subgroup. Appendix D compares the effect on the recovery time schedule and dose history of personnel of using three commonly accepted decay rates. Appendix E compares the effect on the recovery operation of using a different set of dose restrictions. Appendix F compares the effort and time required for recovery of small refineries and large refineries.

SECTION 2

ESTIMATION OF EARLIEST ENTRY TIMES

2.1 GENERAL

This section is concerned with the estimation of earliest entry times for the first step of the recovery problem explained in 1.3.3. The section discusses the parameters that govern earliest entry time, describes the computational procedure used in the analysis, presents estimates of earliest entry times for several combinations of parameter values, and investigates the sensitivity of the entry times to changes in the values of the controlling parameters.

As noted in 1.3.1, after the fallout period and before plant personnel can leave shelter or return to the refinery to start decontamination, there may be a delay of days or weeks until the radiation intensity in the vital area is reduced by radioactive decay to such a level that decontamination personnel will not accumulate doses that are larger than the maximum doses specified in the problem (1.1). In this study, earliest entry time is defined as the earliest time, in days after burst, at which personnel can start decontamination without accumulating doses that will exceed any of the dose restrictions. During nonwork hours, personnel are assumed to retreat to shelters or a staging area where they receive negligible doses.

2.2 PARAMETERS

The earliest entry time depends on the particular combination of governing-parameter values. These are the dose restrictions, standard intensity, radioactive decay rate, personnel work schedule (hours per shift per day), and the reduction of intensity in the vital area as decontamination progresses. In this study, with the liberal dose restrictions imposed and with the relatively high density of decontamination work force, the earliest entry time was found to be not significantly dependent on the type or size of the installations. Used in the computations were the specified dose restrictions, the range of standard intensities given in 1.5.2, the decay rate of Ref. 1, and work schedules of 4 hr and 8 hr per day. The estimates computed in this study are generally applicable to any refinery.

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Only an approximate determination of earliest entry time can be made with presently available data. For example, the computation of earliest entry time depends on the reduction in the vital-area intensity not only by radioactive decay but also by decontamination. There will be some reduction each day of decontamination. For the vital area of a given refinery, the amount of reduction by decontamination may vary widely and therefore cause the earliest entry time to vary. To illustrate, consider the earliest entry time for a standard intensity of 10,000 r/hr, the 30-r/day restriction, and an 8-hr workday. If there is no decontamination, or a residual number of 1.0, the earliest entry time would be 33 days; if the average reduction during the first day of decontamination is 0.5, then the earliest entry time would be 19 days. Because of the inability to more accurately predict the residual number during the decontamination phase, estimates of earliest entry times are not very accurate.

2.3 ILLUSTRATIVE EXAMPLE

To illustrate the procedure adopted in determining the earliest entry times, a specific case will be considered. The computations will be carried out in detail for one point and the complete results for this case will be shown graphically. In this illustrative example, the dose restrictions are those previously assumed--30 r/day, 230 r/2 wk, and 1000 r/yr. It is further assumed that no decontamination is performed.

The time of entry for a given dose restriction is obtained from Table E.1, Appendix E, where the accumulated doses for continuous occupancy of various durations and for a standard intensity of 1000 r/hr at 1 hr are tabulated. For example, one can read directly from this table that a person entering a field of 1000 r/hr at 1 hr on the 14th day after a burst, and remaining there for 2 weeks (24 hr/day) will receive a dose of 230 r (one of the dose limits set for the report). (If the standard intensity were 10,000 r/hr at 1 hr, the corresponding 2-week dose would be 2,300 r; likewise, a standard intensity of 100 r/hr would give a dose of 23 r. The dose accumulated during a given period is reduced if occupancy is not continuous. Thus, in the above case, a person spending only 8 hr/day in the area and the remaining hours in an area of negligible intensity would receive a dose of 230 x 8/24 = 77 r/2 wk. Now, however, the dose is well below (in fact, only 1/3) the allowable dose of 230 r/2 wk. To find the entry time for 8-hr occupancy for the allowable dose, we multiply the continuous occupancy dose by 3, obtaining a value of 690 r/2 wk. Looking at column B, Table E.1, we find that 690 r falls somewhere between 4 and 5 days; linear interpolation indicates a value of 4.7 days.

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Somewhat better interpolation accuracy is obtained, particularly for early times, by obtaining intermediate values from a plot of entry time vs accumulated dose on a semi-logarithmic graph.

In summary, the basic procedure to find the earliest entry time using Table E.1 is:

(1) Multiply the given dose restriction (30 r/day, 230/2 wk, or 1000/yr) by the fraction: 24 hr/work-shift hr.

(2) Multiply (1) by the ratio $\dfrac{1000}{\text{standard intensity}}$.

The reduction in intensity due to decontamination or shielding is also introduced at this point by multiplying the standard intensity by the appropriate residual number.

(3) Find, by interpolation if necessary, the product from (2) in the appropriate column of Table E.1 and read the equivalent earliest entry time.

As an example, consider the case where the dose restriction is 30 r/day, the standard intensity is 30,000 r/hr at 1 hr, and the work day is 4 hr. Find the earliest entry time.

(1) 30 x 24/4 = 180 r/day

(2) 180 x 1000/30,000 ≈ 6.0 r/day

(3) From column A, Table E.1, the earliest entry time is found to be just over 6 weeks, actually 42.5 days.

2.3.1 Results

Earliest entry times, T_m, for 4-, 8-, and 12-hour workdays and for allowable doses of 30 r/day, 230 r/2 wk, and 1000 r/yr, are shown in Figs. 1, 2, and 3, respectively. These curves are earliest entry times for the stated dose restrictions and assume no decontamination. An overlay of these three graphs (Fig. 4) shows that the limiting dose restriction varies with standard intensity and length of work shift.

2.4 TABULATION OF EARLIEST ENTRY TIMES FOR DOSE RESTRICTIONS OF 30 r/DAY, 230 r/2 WK, AND 1000 r/YR WITH DECONTAMINATION

The results of the analysis show that the 30 r/day dose restriction controls the earliest entry time when decontamination is to be

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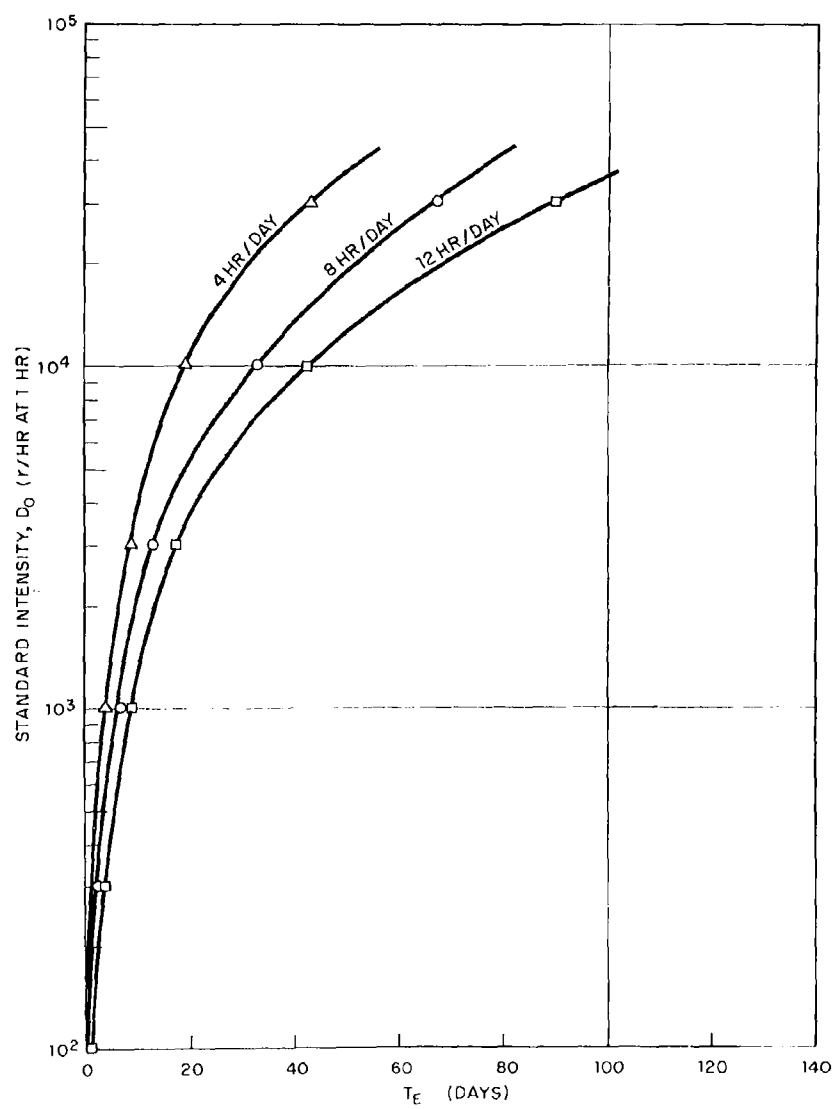
Fig. 1   Earliest Entry Time for an Allowable Dose of 30 r/Day

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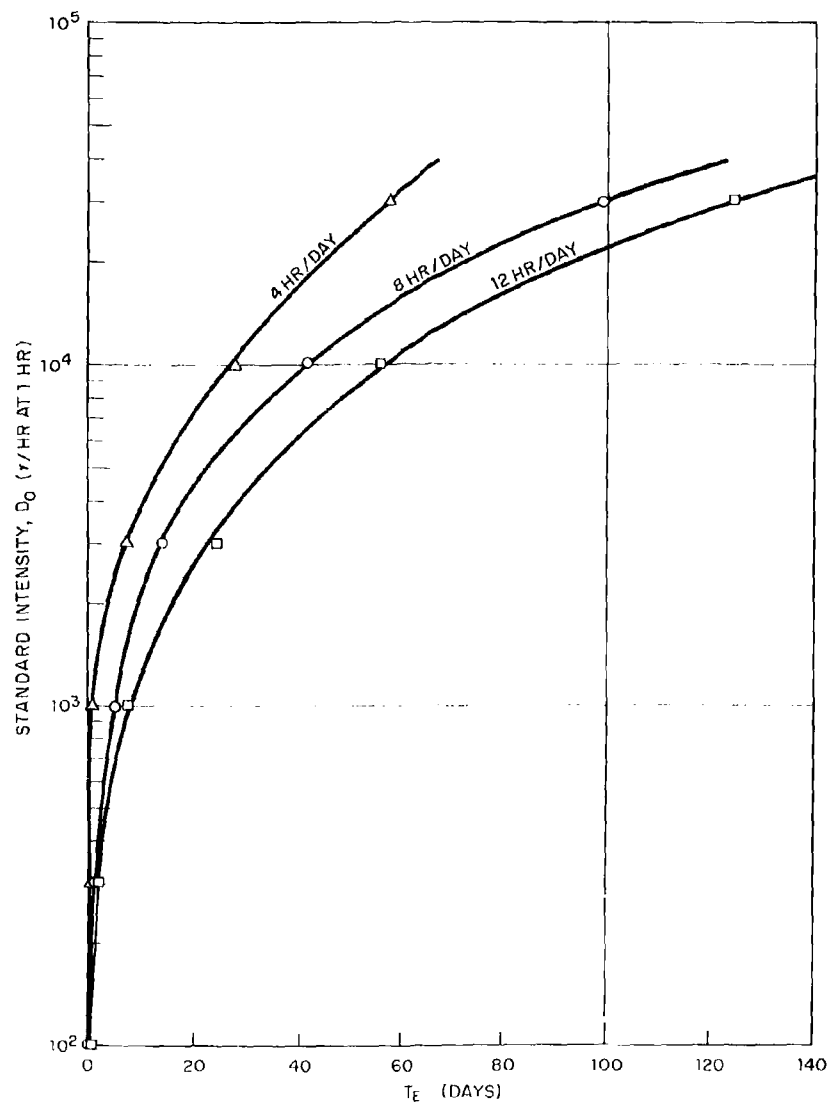
Fig. 2   Earliest Entry Time for an Allowable Dose of 230 r/2 Wk

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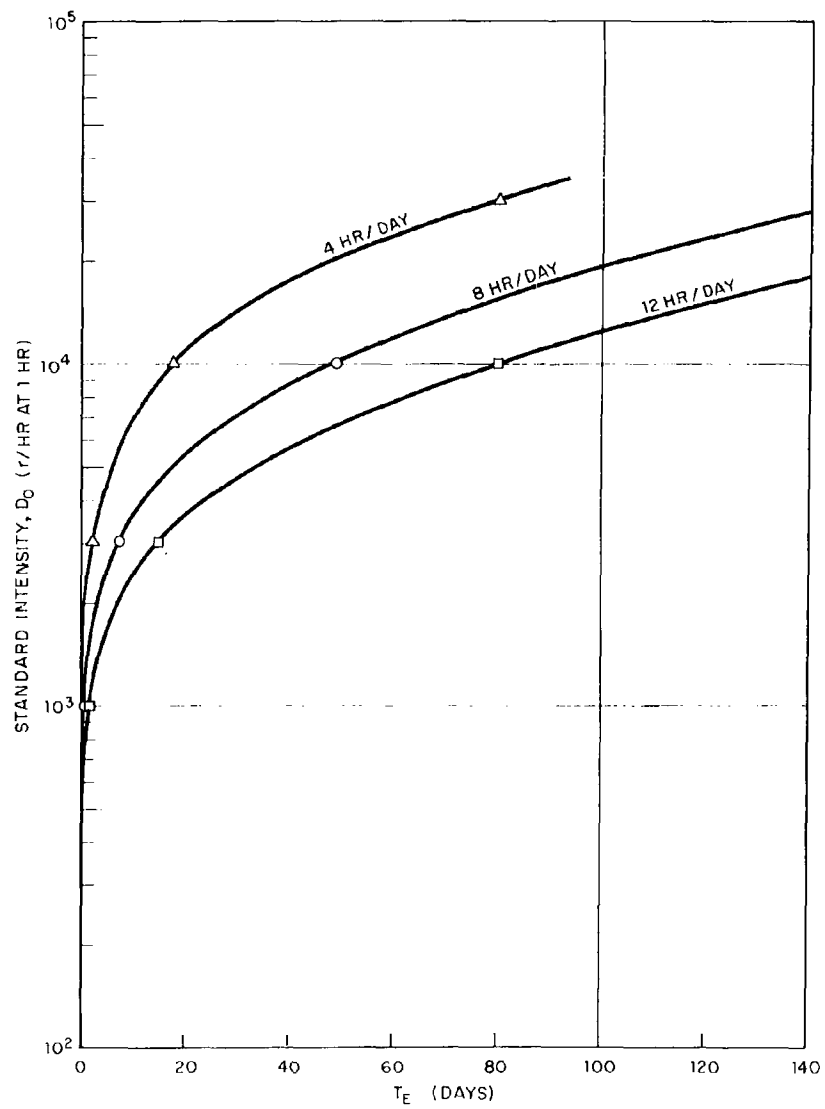
Fig. 3   Earliest Entry Time for an Allowable Dose of 1000 r/Yr

18
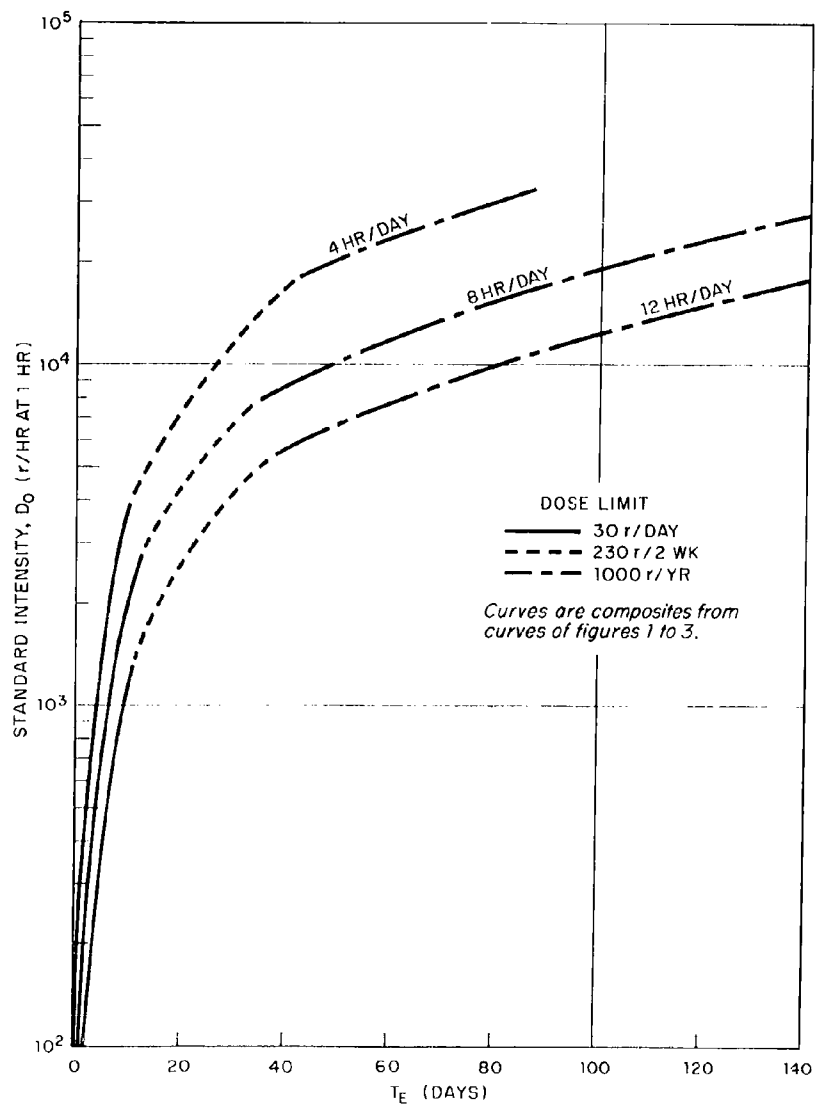
Fig. 4   Earliest Entry Time for Combined Dose Restrictions
vs Various Standard Intensities

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performed. In other words, for these cases, if the dose limitation of 30 r/day is not exceeded on the first day, then the dose restrictions of 230 r/2 wk and 1000 r/yr are not exceeded. By a method similar to the one just explained, earliest entry times have been determined for this set of dose restrictions. Here, the decrease in radiation intensity as the decontamination progresses has to be considered, as well as the final value of the residual number achieved by decontamination. Four cases have been considered in this illustrative example. Besides the value of the standard intensity, the values of one or more of the other controlling parameters of the earliest entry time have been allowed to change. These parameters are:

F_T = the fraction of day worked by the decontamination crew;

F_D = an average value of the residual number during the decontamination period;

F_T' = the fraction of day worked during the repair and subsequent periods;

F_D' = the residual number for the vital area achieved by decontamination.

The earliest entry times for the cases in question are given in Table 1.

In 5.3.2 an empirical formula has been developed to give similar values for cases of interest for other combinations and values of the controlling parameters.

2.5 SENSITIVITY OF ENTRY TIME TO CONTROLLING PARAMETERS

It is of interest to consider how the earliest entry times change with the changes in values of the controlling parameters. In Section 3, Table 1 can be considered as a sensitivity table showing how the earlier entry times change with the length of the decontamination work day as well as with the effective residual number prevailing during the decontamination. In addition to the above, sensitivity studies have been conducted to find (1) the effect of the use of other radioactive decay rates on earliest entry times as well as on the recovery schedule as a whole; and (2) the effect of the assumption of a different set of dose restrictions on the entry times.

Table 1

Earliest Entry Times in Days for 30-r/day,
230-r/2 wk, 1000-r/yr Dose Restrictions

Standard Intensity (r/hr)	CASE			
	I	II	III	IV
100	< 1	< 1	< 1	< 1
300	2	< 1	< 1	< 1
1,000	6	4	4	2
3,000	13	8	8	5
10,000	31	19	19	12
30,000	67	41	42	26

Case	F_T	F_D	F_T'	F_D'
I	8/24	1.0	8/24	0.1
II	8/24	0.5	8/24	0.1
III	4/24	1.0	8/24	0.1
IV	4/24	0.5	8/24	0.1

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2.5.1 Effect of Different Decay Rates

The effect on the recovery schedule and on the earliest entry times, in particular, of using different radioactive decay rates are discussed in detail in Appendix D. The three rates considered are (1) the $t^{-1.2}$ decay law; (2) the one employed in Ref. 1; (3) and the one discussed in Refs. 2 and 3 and identified here as the I (F) decay rate. The conclusion reached is that the recovery schedules computed with any of the three decay rates are not significantly different. The basis of comparison includes the earliest entry times and the accumulated doses of the personnel conducting the recovery.

2.5.2 Effect of Different Set of Dose Restrictions

The sponsoring agency requested that a short analysis be made of the effect of changing the dose restrictions. The modified set of restrictions uses one which limited the accumulated doses to the recovery personnel to 230 r/2 wk and 1000 r/yr with no restrictions on the one day dose. The radiological history of the recovery personnel is considered in detail for this case in Appendix E. Table 2 gives briefly the earliest entry times possible for this case for various combinations of values of the controlling parameters; with the values of entry times shown, the new dose restrictions are not exceeded. Comparison of Tables 1 and 2 gives the effect on the earliest entry time of ignoring the 30-r/day dose restrictions.

Table 2

Earliest Entry Times in Days for 230 r/2 wk,
1000 r/yr Dose Restrictions

Standard Intensity (r/hr)	CASE			
	I	II	III	IV
100	< 1	< 1	< 1	< 1
700	< 1	< 1	< 1	< 1
1,000	< 1	< 1	< 1	< 1
3,000	4	2	3	2
10,000	13	9	11	8
30,000	35	25	32	22

Case	F_T	F_D	$F_T{}'$	$F_D{}'$
I	8/24	1.0	8/24	0.1
II	8/24	0.5	8/24	0.1
III	4/24	1.0	8/24	0.1
IV	4/24	0.5	8/24	0.1

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SECTION 3

ESTIMATION OF DECONTAMINATION EFFORT AND TIME

3.1 GENERAL

This section is concerned with the second step involved in the recovery of a refinery: the estimation of the man-days and the time in days that would be required to prepare a staging area and to decontaminate the vital area so that recovery personnel would not receive doses that would exceed the specified dose restrictions given in 1.1. Contained in this section are brief discussions of the staging area, the vital area, and refinery surfaces and applicable decontamination methods; a description of the computational procedure used; and the computed estimates.

3.1.1 Staging Area

A staging area to serve as a base of operations would normally be located in or near the refinery. The staging area would be occupied during nonwork hours by decon, repair, and operations personnel. An existing structure that could be converted to quarters would be ideal. A more temporary staging area could be set up in an open field. If available, large underground shelters or even ships moored in an adjacent body of water* could serve as staging areas. However, whatever the choice for a staging area, its radiation intensity must be reduced to minimal levels for the safety of the personnel occupying it during nonwork hours. The topic of staging areas is considered in detail in Ref. 1. In that reference, it is estimated that a residual number of .001 can be achieved for an offshore staging area. By an

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* A ship if washed down would provide a staging area of low hazard because radiation intensity over water decreases rapidly due to dispersion of contaminant in the water and to attenuation of the radiation by the water.

offshore staging area is meant a staging area located on a moored ship possibly a short distance from land or a wharf surface extending into a river or ocean. Many refineries are located near such bodies of water, and tankers are moored near the refinery docks for loading and unloading of petroleum products. Offshore staging areas would be possible in such cases.

The second type of staging area would be located in an open area or a modified building in or adjacent to the refinery. Using a cleared area or a modified building within the radiation field could give a residual number of 0.010. To prepare such a staging area would require a combination of radiological countermeasures: reclamation and shielding. A decontamination buffer zone of several hundred feet in width around the entire staging area, or shielding with sandbags, would be necessary to achieve the desired residual number.

The time required to prepare a staging area will depend on such factors as its size, work-force size, experience of the work force, nature of the surfaces to be reclaimed, reclamation method or methods used, reclamation rate, and kind and amount of shielding protection required. In general, these factors can vary considerably. However, according to Ref. 1, it should not take more than 24 hours, using refinery personnel, to prepare a staging area for any-sized refinery.

3.1.2 Vital Area

The vital area contains the essential processing facilities and functions and will usually require continuous occupancy. The vital area will contain the major refinery equipment and systems, the boiler plant, the packaging and loading facilities, the shops, and the essential administrative offices. Not included in the vital area are facilities that serve useful purposes but do not require continuous occupancy--such as tank farms, open storage areas, and waste disposal areas. The tank farms, which are usually spread out and not paved, would be difficult to decontaminate. Hence, the preferred counter-measure to control personnel dosage in this area would be to limit staytimes of those who must enter it. Control of dosage in this area would be helped by decontamination of strategic locations and use of a specially shielded vehicle.

To decontaminate the vital area requires effort and time; during the decontamination period, personnel engaged in this operation are increasing the radiological dose they receive. Consequently, it is advantageous to carefully delineate and limit the extent of the vital area to a minimum size.

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For standard intensities of 1,000 r/hr and less, if entry time
is postponed until the 30-r/day dose restriction is satisfied, it will
not be necessary to decontaminate the vital area, because radioactive
decay would be reducing the intensity sufficiently that accumulated
doses would not exceed either the 2-wk or 1-yr dose restriction. In
an actual situation, it would be advisable in all cases, to attempt
to minimize the dose accumulated by personnel by decontaminating their
work area to the lowest residual number possible--even if this had to
be done over intermittent and extended periods.

3.1.3 Refinery Surfaces and Applicable Reclamation Methods

The discussion below of refinery surfaces and applicable reclama-
tion methods pertains both to a staging area and the vital area.

In the refineries visited, most of the roof surfaces were of com-
position sheeting and sheet metal. Firehosing would normally be used
to decontaminate these surfaces. However, the grounds had a wide
variety of surfaces--pavement, hard-packed soil, loose soil, gravel,
etc. Each of these different surfaces would require a different method,
or combination of methods, of removing the contaminant. Each refinery
had a unique combination of surfaces and areal arrangement.

In some refineries, most of the grounds are paved and could be
easily decontaminated by firehosing provided the layer of contaminant
is not too thick, say 0.1 inch. If it is thicker, decontamination
would have to be done by front-end loader, or hand shoveling, followed
by firehosing. However, if the latter combination method is used, the
overall decontamination rate would be considerably slower and there
could arise a removal problem if the drainage system could not handle
the large mass of contaminated material flushed to the drains.

In other refineries, the grounds are mostly unpaved--some
are hard-packed soil, some are loose soil. These unpaved grounds would
be relatively difficult to reclaim. For the hard-packed soil, removal
of the contaminant would be done by motorized sweeping or by hand
sweeping and shoveling, depending on the size of the area and the
surface-roughness conditions. For the loose soil, removal of the con-
taminant would be done by motorized or towed scraper, or if such
equipment is not available, by some manual method, such as shoveling.

It was observed, in general that larger refineries have much
better housekeeping practices than smaller refineries. Thus, reclama-
tion of the vital areas of these larger refineries would be easier.

In regard to the availability of water for decontamination, the larger refineries observed have abundant, well-distributed water supplies normally used for refinery processes and firefighting. Also, these refineries are located near large bodies of water that could provide an emergency source for decontamination. In contrast, many of the smaller refineries observed (in southern California) do not have such abundant water supplies and many are located far from bodies of water.

3.2 COMPUTATIONAL PROCEDURE AND ESTIMATES

In the computation of man-days and time in days required to reclaim the vital area, the following parameters were taken into account: standard intensity, vital-area size, reclamation methods, reclamation rates, work-force size, and work schedule. Also taken into account were the assigned parameter values given in 1.5.2 and the pertinent simplifying assumptions of 1.5.1.

Information obtained from the refineries that was pertinent to reclamation was analyzed to see if a general pattern existed. Some parameters, namely work-force size and vital-area size, were found to be related to refinery size. In Fig. 5, the total number of people employed by the refineries contacted, obtained from Item 3 of the Questionnaire, has been plotted against the size of the refineries, obtained from Ref. 4. This relationship could be approximated by a straight line on log-log paper. A second line, titled 75% of total employees, corresponds roughly to "productive workers," -- those directly concerned with the operation of the refinery. Vital-area sizes were determined by delineating the areas on maps or photographs furnished by the refineries, and then measuring the areas. Figure 6 shows vital-area size plotted against refinery size.

Reclamation methods and rates, based on NRDL field tests, are given in Table 3. The values are based on Refs. 1 and 5.* The residual numbers tabulated are obtained under ideal test conditions -- large paved areas, etc., and are much lower than one would obtain in decontaminating areas of the type one would encounter in oil refineries. In addition, the NRDL experiments have been conducted with mass loading of fallout debris of 100 to 200 g/ft^2 corresponding to standard intensities of roughly 2000 to 4000 r/hr; in this study, standard intensities of 30,000 r/hr are considered. It has been necessary to

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* Also on a memorandum for files of 6 Feb 1961 by L.W. Owen, USNRDL.

Table 3

Logistics, Rates, and Residual Numbers for Several Reclamation Methods

Method	Principle of Operation	Applicability	Men and Equipment Per Team	Observed Rate Per Team (ft²/hr)	Planning Effort in Man-Hr[a] (10⁴ ft²)	Residual Number
Firehosing	Water under pressure pushes contaminated dirt into drainage system.	All roofs, walls, and paved areas.	3-men/1-1/2" firehose, using 100 gpm at 75 psig.	35,000[b]	6	0.08 for I_o = 300 r/hr 0.05 for I_o = 1000 r/hr 0.02 for I_o = 3000 r/hr
Firehosing plus scrubbing	Firehosing alternated with mechanical loosening of contaminant.	Large paved areas.	4-men/1-1/2" firehose; 2 men with brushes	5,000[c]	14	0.04 for I_o = 300 r/hr 0.02 for I_o = 1000 r/hr 0.01 for I_o = 3000 r/hr
Mechanical sweeping	Loosening of contaminant by a rotary broom and simultaneous collection.	Large, open paved and hard-packed areas.	1 street sweeper with 80" broom and 2-4 yd³ hopper 1 operator	100,000[d]	2[e]	~ 0.01
Hand sweeping and shoveling	Accumulation of contaminant by push broom; collection by shovel and wheelbarrow.	Small paved or hard-packed areas.	2 men with broom, 1 man w/shovel, 1 man w/barrow	4,000-10,000[d]	15	~ 0.05
Mechanical surface removal	Remove 2-3" of surface material and carry to nearby disposal site.	Small areas of loose gravel, loose or packed dirt, or vegetation.	1 scraper and operator, 1 front-end loader, 1 man with shovel	3,000-6,000[d]	15	~ 0.1
Manual surface removal	Remove 1-2" of surface material and carry to disposal site.	Very small, cutup areas of loose gravel, etc.	3 men with shovel, 1 man with wheel-barrow	1,000-2,000[d]	50	~ 0.1

[a] Planning effort accounts for disposal of debris, rest periods, equipment maintenance, and operational delays.

[b] See Ref. 5.
[c] See Ref. 1.
[d] See 3.2.

[e] For 2 passes over the area and an initial contaminant layer equivalent to 5000 r/hr at 1 hr.

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extrapolate from values such as these to operational conditions and to more intense radiation intensities with insufficient data. The choice of a given method for decontamination and reclamation is dependent upon two inherent features of the individual refinery: the type of surface to be reclaimed and the equipment and supplies that are available. In the refineries visited, considerable spread in these two features existed; thus, a unique solution could not be obtained. However, it was deemed feasible to relate a range of values for radiological recovery methods to refinery size. This was done for recovery effort, by selecting firehosing of paved areas as a lower limit and manual surface removal of dirt surfaces as an upper limit, and then applying the appropriate planning effort data from Table 3 to the vital areas shown in Fig. 6. The lower and upper curves in Fig. 7 indicate these extremes that might be required in the reclamation effort of any oil refinery.*

The time required for reclamation can be estimated from the effort values of Fig. 7 as follows:

$$\text{Time in days for reclamation} = \frac{\text{Effort in man-days}}{\text{Available manpower}} \times \frac{\text{Shift length in hours}}{24 \text{ hours}}$$

The available manpower was assumed to follow the 75% curve of Fig. 5 and the shift length was taken as 4 hours. The resultant time in days vs refinery size in B/D for the 2 methods, is shown in Fig. 8. The decrease in decontamination time with increasing refinery size can be attributed to the relatively larger work force in larger refineries. A mass loading of approximately 150 g/ft^2 (equivalent to 3000 r/hr at 1 hr) was assumed for Figs. 7 and 8.

The above analysis assumes the attainment of a decontamination residual number of 0.1, which seems realistic on the basis of field tests on residential complexes. However, adequate data directly applicable to the decontamination problems likely to be encountered in a refinery are not available, and until suitable field tests can be conducted, values given for effort and time should be considered as tentative.

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* For the refineries visited, the relationship did not approach either of these extremes, but was more nearly like the intermediate case shown in the figure.
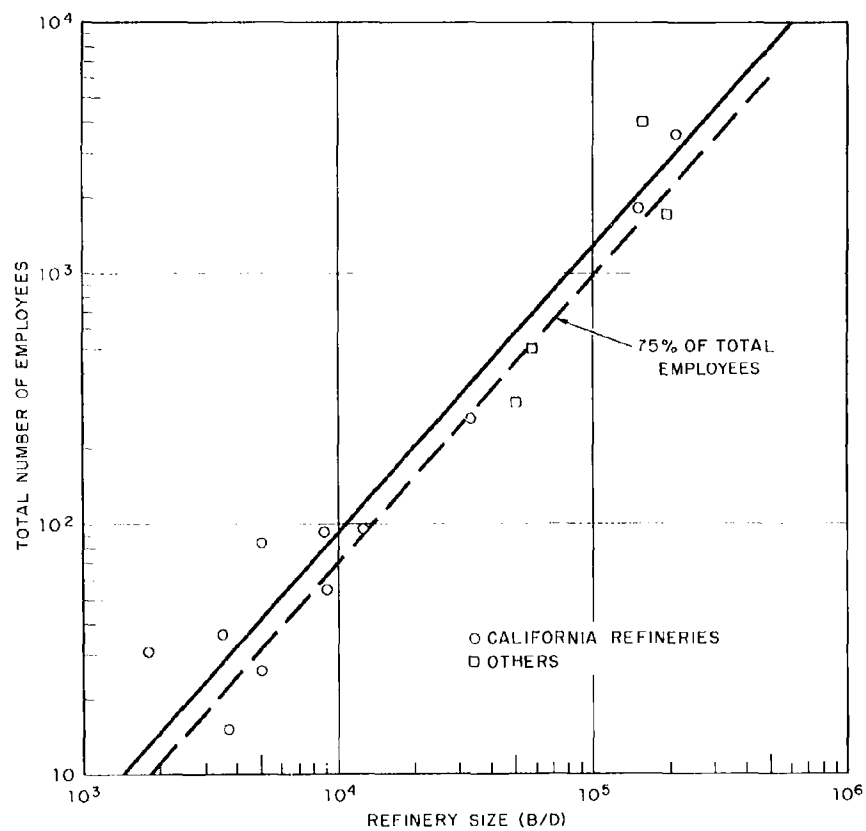
Fig. 5   Total Number of Employees vs Refinery Size

Fig. 6 Vital Area vs Refinery Size

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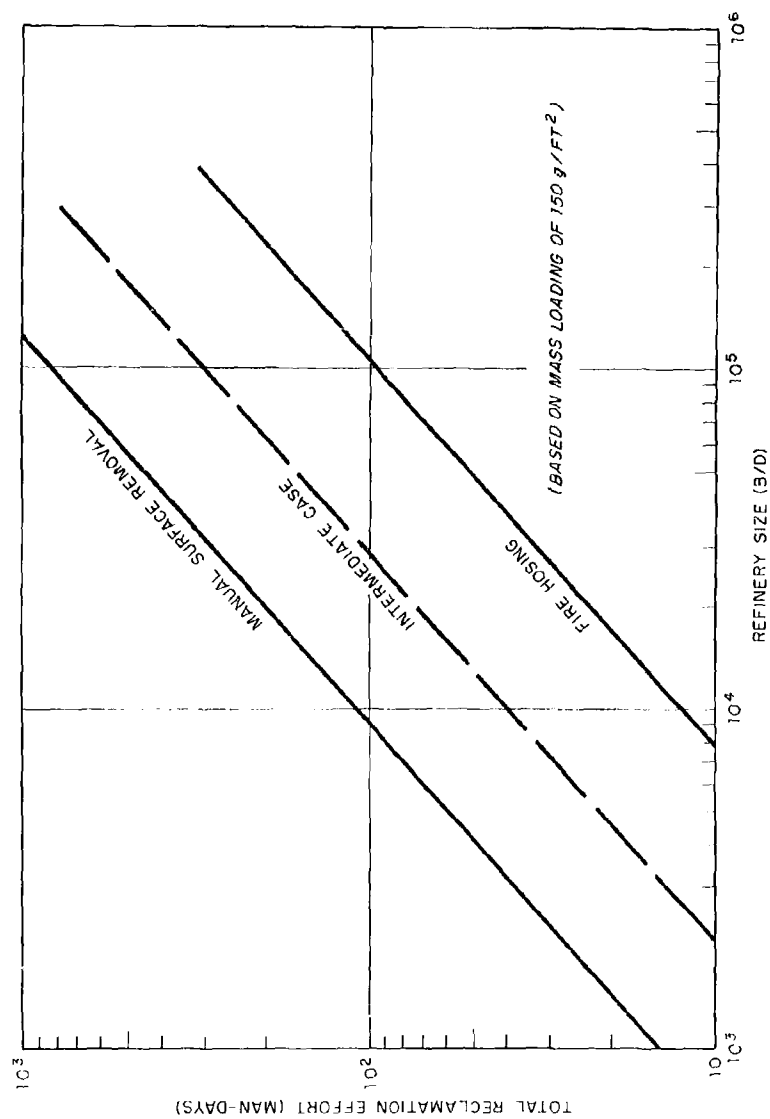
Fig. 7 Total Reclamation Effort vs Refinery Size

(BASED ON MASS LOADING OF 150 g/FT²)

MANUAL SURFACE REMOVAL

INTERMEDIATE CASE

FIRE HOSING

REFINERY SIZE (B/D)

TOTAL RECLAMATION EFFORT (MAN-DAYS)

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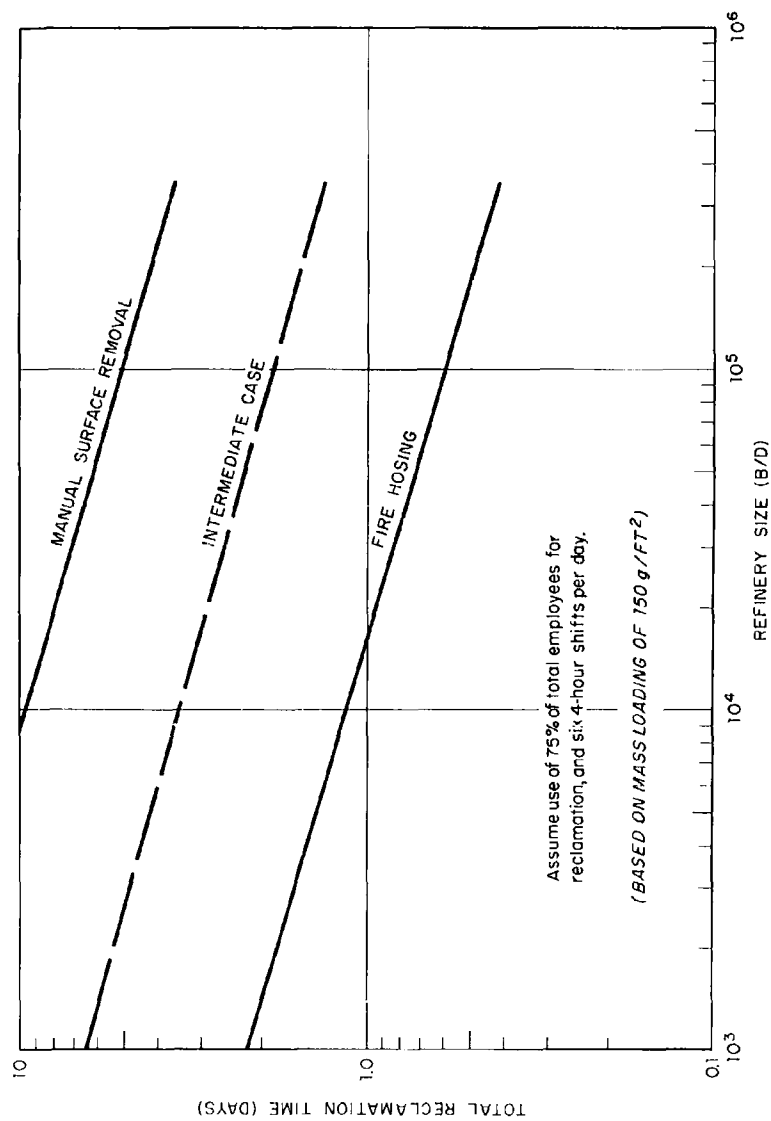
Fig. 8   Total Reclamation Time vs Refinery Size

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SECTION 4

ESTIMATION OF REPAIR MAN-DAYS AND TIME

4.1 GENERAL

Under routine conditions, it requires from 24 to 48 hours to shut down all the units of a medium-size refinery. For the nuclear-attack situation considered in this study, this shutdown-time will be sharply reduced. Plant equipment will be damaged and will require repairs before production can be resumed. Since it is impossible to predict the probable shutdown time, a range of 3 values--1 hour, 3 hours and 6 hours--is considered in this study. The shutdown operation should be completed before the arrival of fallout at the plant, because the dose-accumulation rate is extreme during fallout deposition and for some time after fallout cessation. Therefore, because of radioactive contamination of the plant, it will be necessary to delay the start of repairs for anywhere from a few days to many weeks after fallout cessation, depending on the standard intensity. Then, after radiological recovery, it will take considerable time to complete repairs, depending on the amount of damage sustained.

4.2 BASIC DATA AND PRELIMINARY TREATMENT

Item 6 of the Questionnaire (see Appendix C) was directed toward obtaining information from refineries in the subgroup (see 1.4.2) that would enable estimation of the man-days and the time in days needed for repairs. Before preparing Item 6, the subject was discussed with qualified personnel of local major Western oil refineries. Accordingly, it was decided that the two characteristics of a refinery that could most greatly affect the number of man-days required for repairs after fast shutdown would be the size and the complexity of the refinery. These characteristics could be determined for all the refineries in the U.S. using the "complexity index" developed by Nelson.[6] This index is obtained by summing the product of the daily volume of each petroleum product manufactured and the cost of the equipment and processing per barrel, and dividing the sum by the refinery size.

The Questionnaire was mailed to each refinery of the subgroup, and several weeks later the investigators visited each refinery to discuss and pick up the completed questionnaire. In most cases, the repair information requested had been carefully prepared by qualified personnel. Personnel of the smaller refineries were of the opinion that, following repairs, production would be up to normal and therefore gave only the man-days required for 100% production.

The repair data obtained by Item 6 are presented in Figs. 9 through 14 in almost the original form that they were obtained from the refineries. The figures show plots of man-days required to achieve 100% production vs refinery size, for 1-hr, 3-hr, and 6-hr shutdown times. The original data points have been included to show the spread in the estimates which reflects the inherent uncertainty in the data. Similar curves for achieving 30% and 10% production were obtained but are not shown here in their original form.

An attempt was made to correlate the repair effort with the complexity index for refineries of approximately the same size. No correlation was apparent, and hence, the complexity index was no longer considered in the analysis of repair effort. The reason why the effect of refinery complexity was not felt more strongly is obscure. It may have been due to a variety of causes--inability of the refinery personnel to give more accurate estimates, insensitivity of repair effort to complexity of operations.

4.3 AVERAGE REPAIR EFFORT FOR VARIOUS PRODUCTION CAPACITIES

Figures 15 through 17 show the average repair effort in man-days vs the size of the refineries in barrels per day for the three shutdown times and for 100%, 30%, and 10% recovery of normal production capacity. The average repair effort is the arithmetic mean of the pessimistic and optimistic estimates given by the refineries. By percent recovery is meant the ratio of the capability of a refinery to process a given volume of crude oil in barrels per day at a particular point in its recovery, to its normal capability. It is to be noted that the curves shown in these figures are not extended to refineries smaller than about 10,000 B/D. Refineries smaller than this are usually asphalt-producing plants and do not contribute much to the total fuel production. Although the trend portrayed by the curves is followed by these smaller refineries--i.e., the repair effort decreases as the refinery size decreases--for refineries smaller than 10,000 B/D, the trend behaves erratically.

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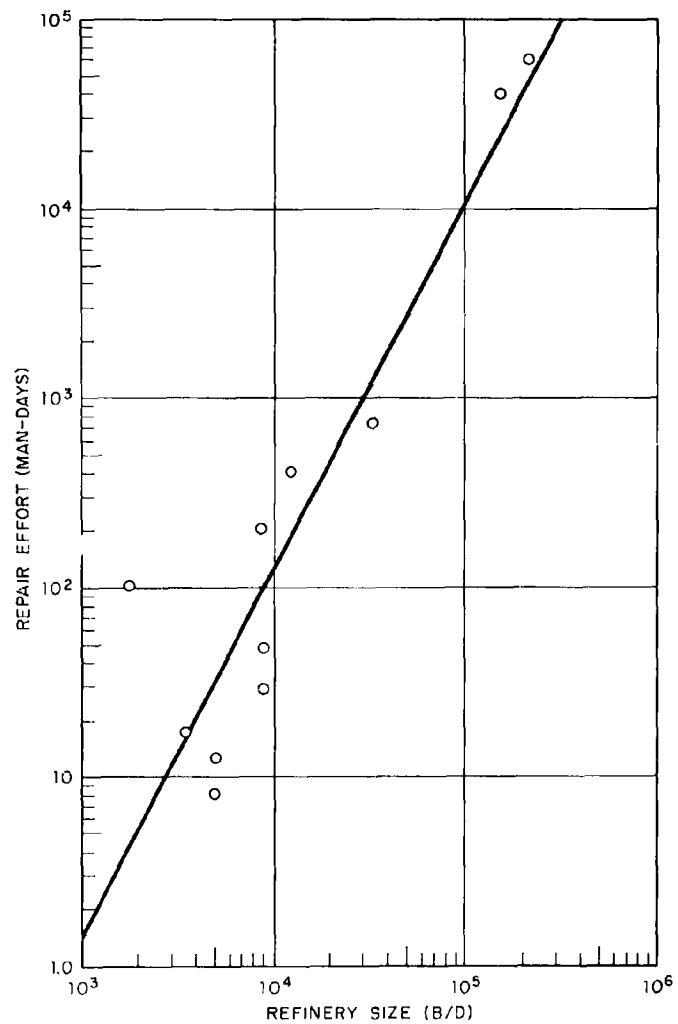
Fig. 9 Repair Man-Days to Achieve 100% Production Capacity
vs Refinery Size for 1-Hr Shutdown Time: Optimistic Estimate

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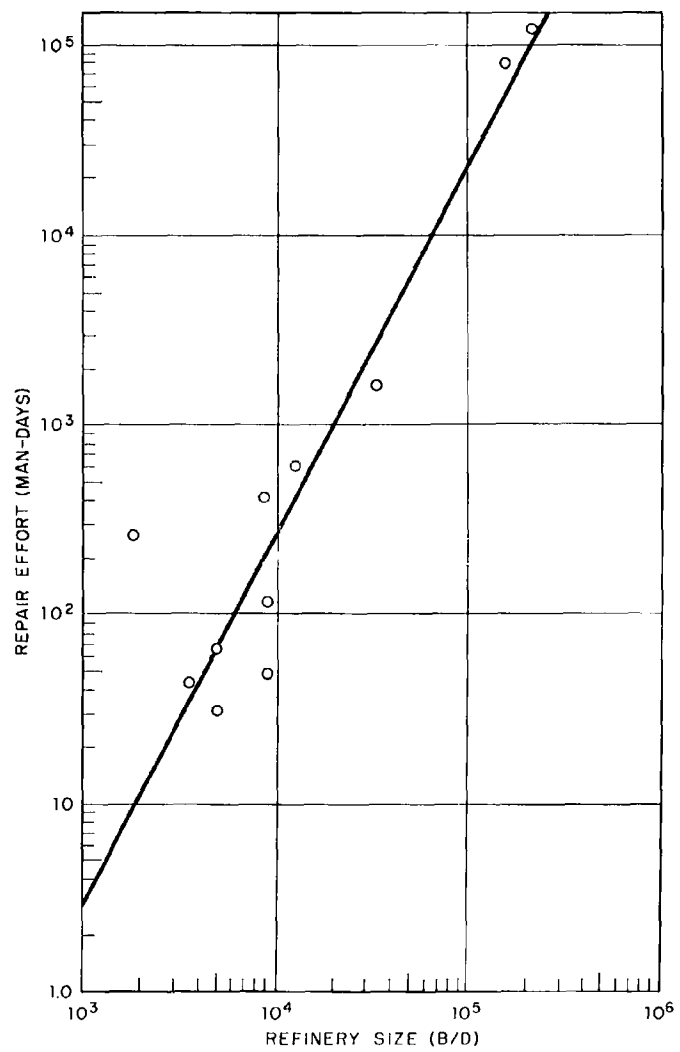
Fig. 10 Repair Man-Days to Achieve 100% Production Capacity
vs Refinery Size for 1-Hr Shutdown Time: Pessimistic Estimate

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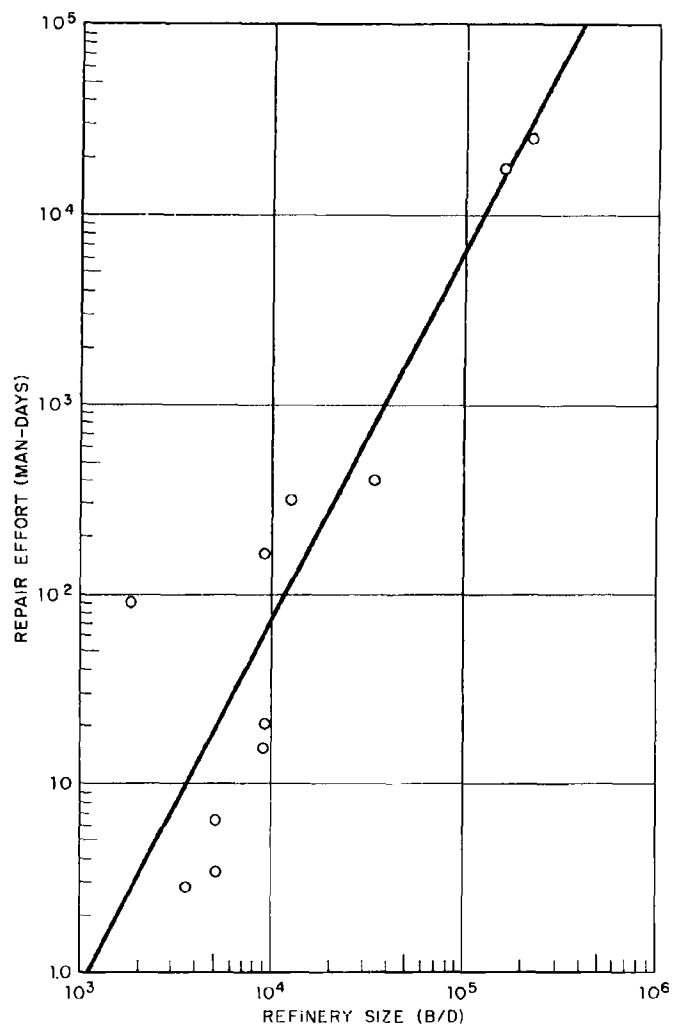
Fig. 11 Repair Man-Days to Achieve 100% Production Capacity
vs Refinery Size for 3-Hr Shutdown Time: Optimistic Estimate

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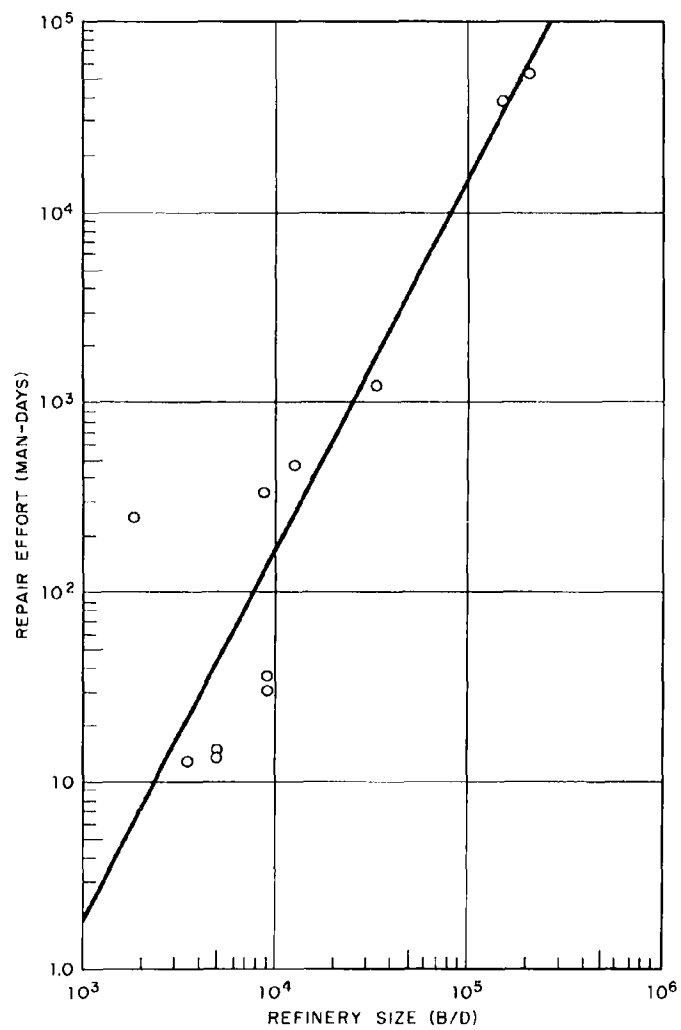
Fig. 12 Repair Man-Days to Achieve 100% Production Capacity
vs Refinery Size for 3-Hr Shutdown Time: Pessimistic Estimate
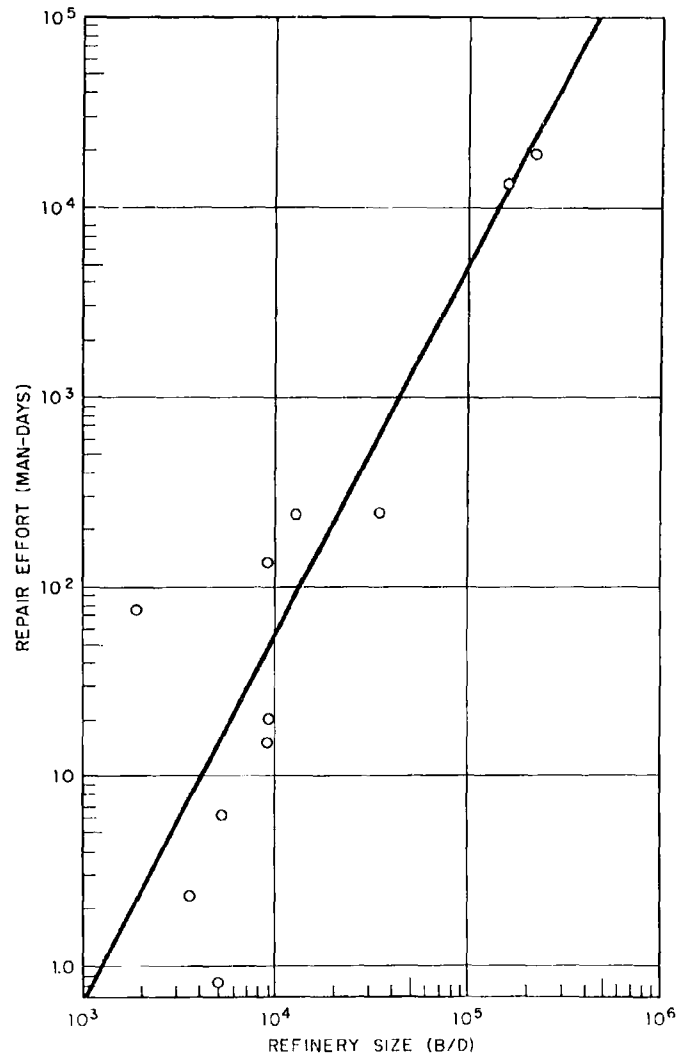
Fig. 13 Repair Man-Days to Achieve 100% Production Capacity
vs Refinery Size for 6-Hr Shutdown Time: Optimistic Estimate
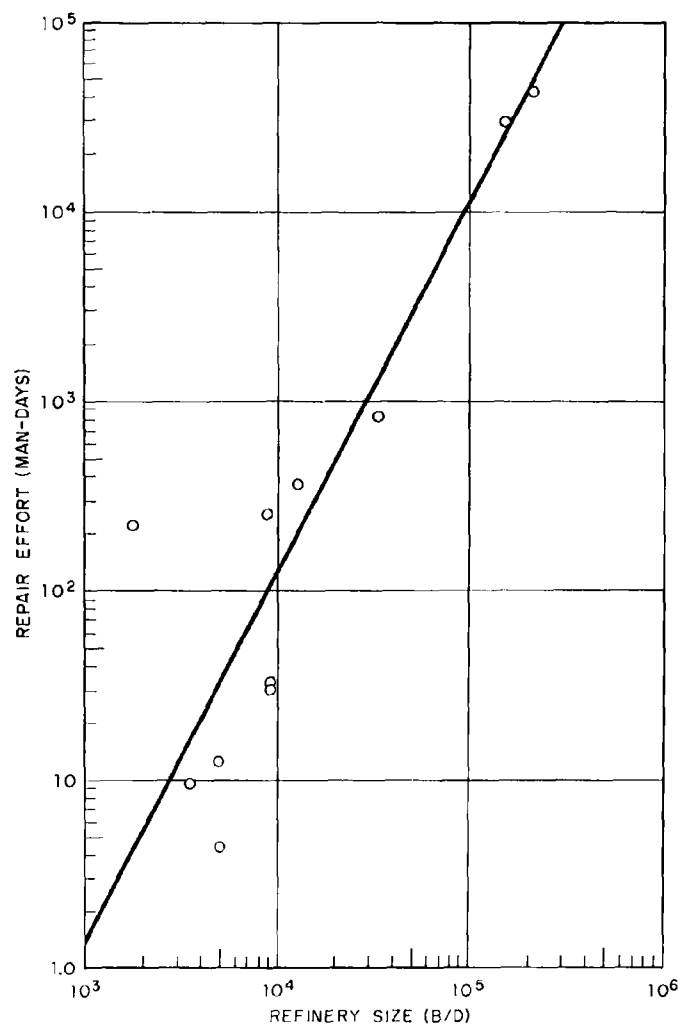
Fig. 14 Repair Man-Days to Achieve 100% Production Capacity
vs Refinery Size for 6-Hr Shutdown Time: Pessimistic Estimate

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4.4 ESTIMATED REPAIR TIME FOR VARIOUS PRODUCTION CAPACITIES

If, for a particular refinery size, one knows the man-days required to perform the repairs, the size of the work force participating, and the work schedule adopted, then one can compute the repair time in days from the following formula:

$$T_R = \frac{E_R}{M \times \frac{h}{24}} \tag{1}$$

where

T_R = number of days required to complete the repairs

E_R = man-days required to repair the refinery (1 man-day = 24 man-hours)

M = total number of personnel participating in repairs

h = number of hours worked per shift.

E_R was read from Figs. 15, 16, and 17; M was read from the 75% curve of Fig. 5; h was taken as 8 hr. With the appropriate values substituted in the above equation for the three shutdown times and for 100%, 30%, and 10% production capacity, T_R was calculated. See Figs. 18, 19, and 20.

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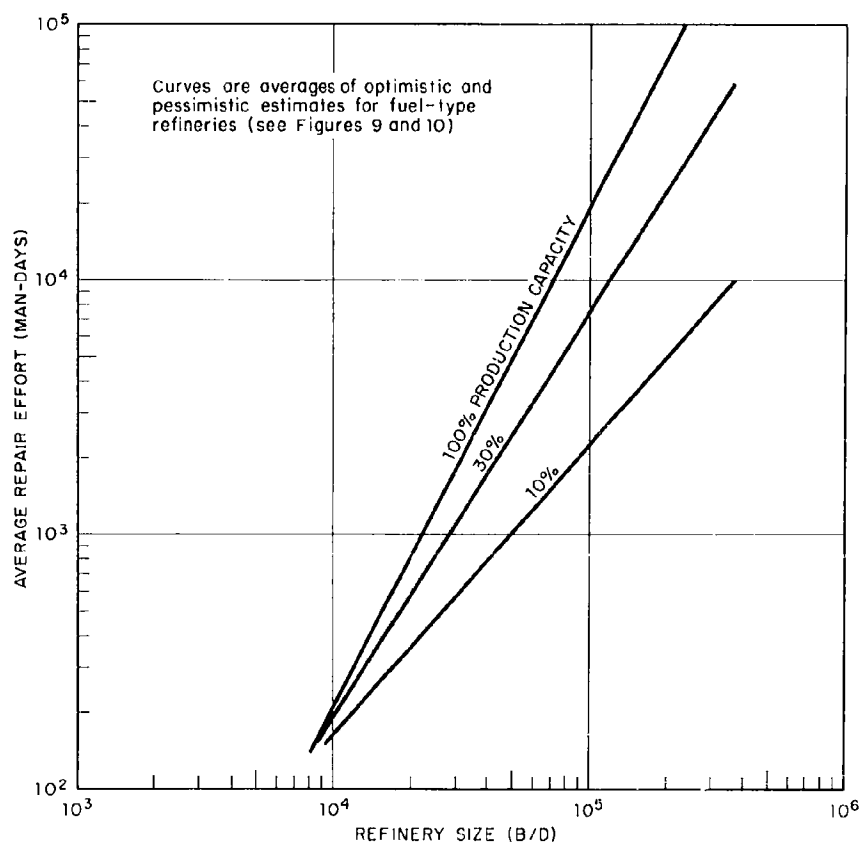
Fig. 15 Average Repair Effort vs Refinery Size for 1-Hr Shutdown Time and Three Production Capacities

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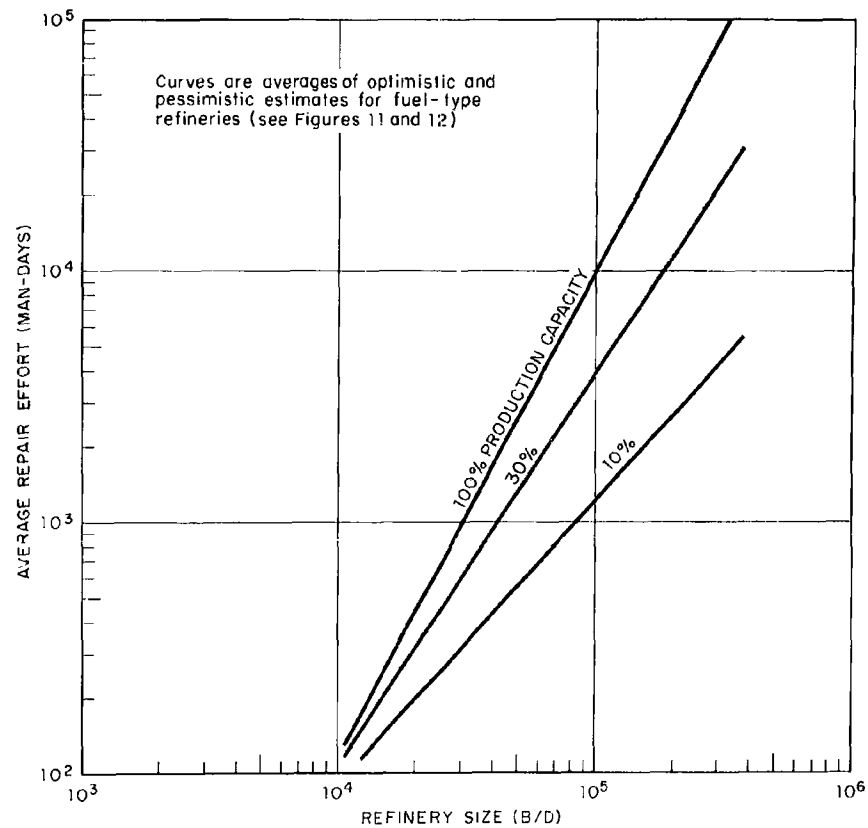
Fig. 16   Average Repair Effort vs Refinery Size for 3-Hr
Shutdown Time and Three Production Capacities
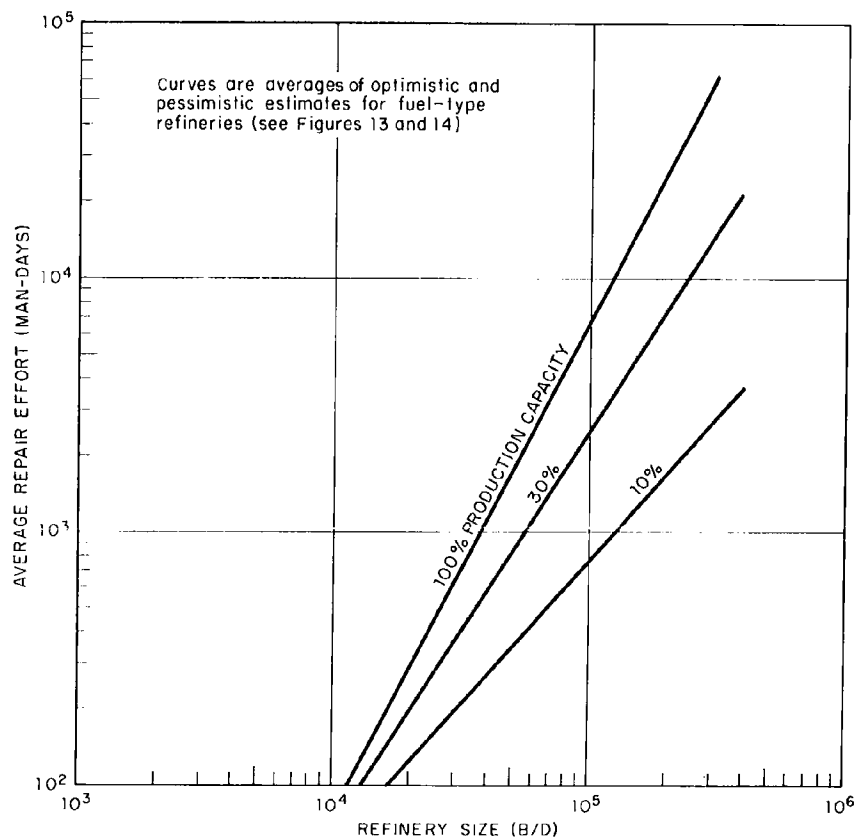
Fig. 17   Average Repair Effort vs Refinery Size for 6-Hr
Shutdown Time and Three Production Capacities

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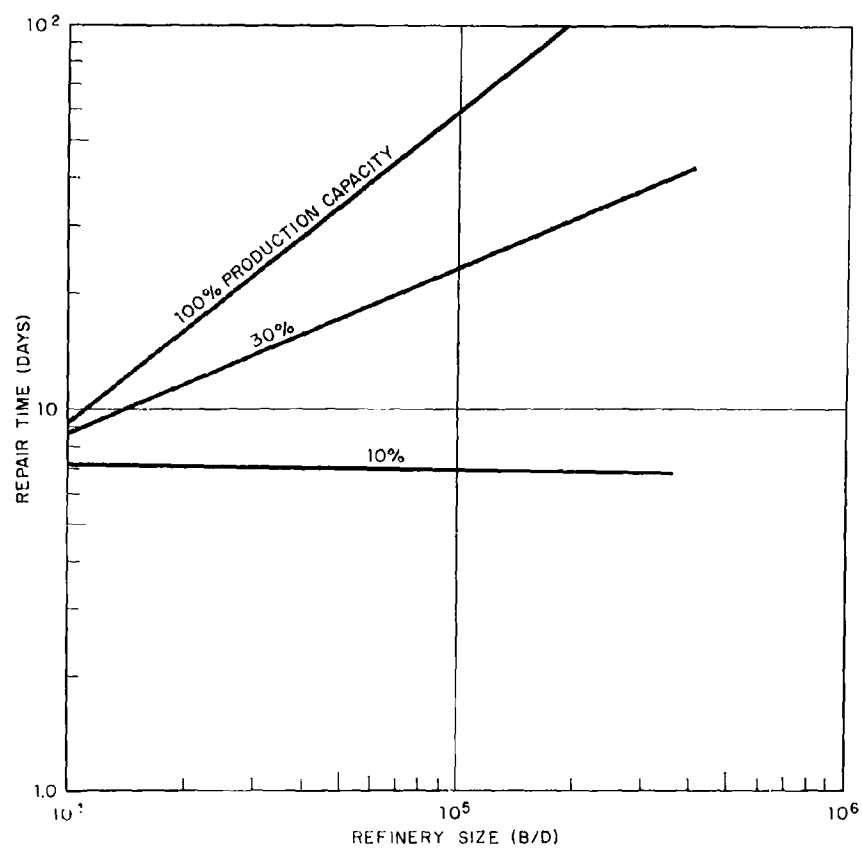
Fig. 18   Estimated Repair Time vs Refinery Size for 1-Hr
Shutdown Time and Three Production Capacities

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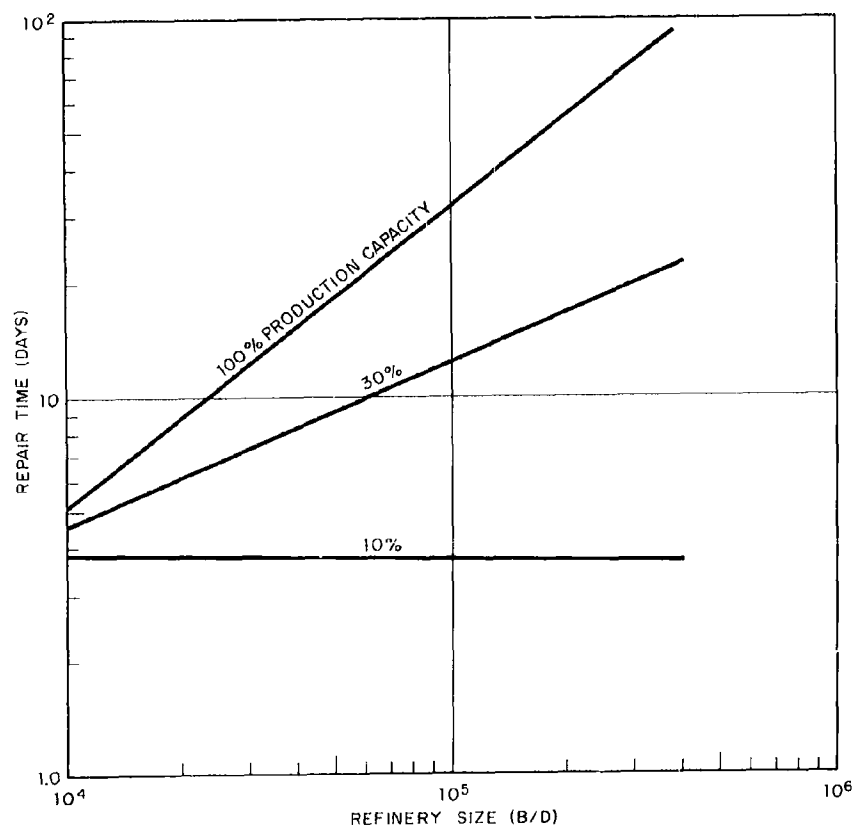
Fig. 19   Estimated Repair Time vs Refinery Size for 3-Hr
Shutdown Time and Three Production Capacities

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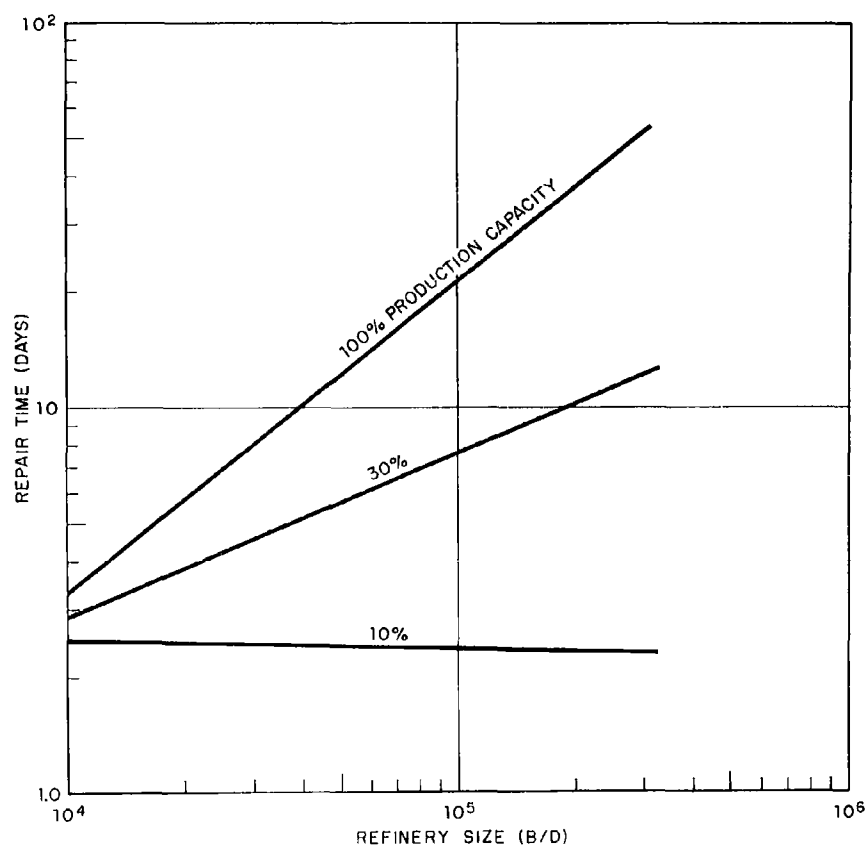
Fig. 20   Estimated Repair Time vs Refinery Size for 6-Hr
Shutdown Time and Three Production Capacities

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SECTION 5

ESTIMATES OF TOTAL EFFORT AND TIME FOR RECOVERY

5.1 GENERAL

This section presents the results that were obtained from the analyses covered in Sections 2, 3, and 4. These results are presented in this section in a form that is most suited for machine computation to determine the total time of availability of resources, T_A. First, the man-days required for radiological reclamation and for repairs are tabulated for the full ranges of standard intensities, shutdown times, percentage production, and refinery sizes. Second, empirical equations are formulated for estimating T_A as the sum of two terms -- repair entry time, T_{ER}, and repair time, T_R. Third, an example is presented to show detailed calculations as an aid in following the computational directions. Finally, to show the order of magnitude of the times required for recovery, the results for an intermediate situation have been tabulated; the intermediate situation is described in Section 5.5.

5.2 TABULATION OF ESTIMATED MAN-DAYS FOR RECLAMATION AND REPAIRS

In Tables 4, 5, and 6 the man-days required for staging area preparation, decontamination of the vital area, and repair of refinery facilities have been tabulated. The values for the man-days required for staging and decontamination are averages based on Fig. 7; the man-days for repairs, from Figs. 15, 16, and 17.

5.3 FORMULATION OF EQUATIONS

5.3.1 General Expression

The time of availability of resources is the time in days after burst at which the refinery attains normal (100%) preattack production capacity. This time can be expressed as:

Table 4

Total Man-Day Effort for 100% Recovery of Various
Size Refineries

(1 man-day = 24 man-hr)

Standard Intensity (r/hr at 1 hr)	Shut-down Time (hr)	Activity	Refinery Size (B/D)					
			5000	15,000	40,000	80,000	150,000	250,000
100 300 1000	1	Staging Repair Total	3 70 73	10 460 470	29 3200 3200	65 12,000 12,000	130 42,000 42,000	240 115,000 115,000
	3	Staging Repair Total	3 40 43	10 250 260	29 1600 1600	65 6300 6400	130 21,000 21,000	240 57,000 57,000
	6	Staging Repair Total	3 20 23	10 160 170	29 1100 1100	65 4300 4400	130 15,000 15,000	240 40,000 40,000
3000 10,000 30,000	1	Decon* Repair Total	15 70 85	63 460 520	180 3200 3400	390 12,000 12,000	810 42,000 43,000	1400 115,000 116,000
	3	Decon* Repair Total	15 40 55	63 250 310	180 1600 1800	390 6300 6700	810 21,000 22,000	1400 57,000 58,000
	6	Decon* Repair Total	15 20 35	63 160 220	180 1100 1300	390 4300 4700	810 15,000 16,000	1400 40,000 41,000

*   Includes staging-area and vital-area decontamination.

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Table 5

Total Man-Day Effort for 30% Recovery of Various Size Refineries

(1 man-day = 24 man-hr)

Standard Intensity (r/hr at 1 hr)	Shut-down Time (hr)	Activity	Refinery Size (B/D)					
			5000	15,000	40,000	80,000	150,000	250,000
100 300 1000	1	Staging Repair Total	3 70 73	10 370 380	29 1700 1700	65 5300 5400	130 14,000 14,000	240 32,000 32,000
	3	Staging Repair Total	3 40 43	10 200 210	29 940 970	65 2800 2900	130 7500 7600	240 17,000 17,000
	6	Staging Repair Total	3 20 23	10 120 130	29 590 620	65 1800 1900	130 4800 4900	240 11,000 11,000
3000 10,000 30,000	1	Decon* Repair Total	15 70 85	63 370 430	180 1700 1900	390 5300 5700	810 14,000 15,000	1400 32,000 33,000
	3	Decon* Repair Total	15 40 55	63 200 260	180 940 1100	390 2800 3200	810 7500 8300	1400 17,000 18,000
	6	Decon* Repair Total	15 20 35	63 120 180	180 590 770	390 1800 2200	810 4800 5600	1400 11,000 12,000

* Includes staging-area and vital-area decontamination.

Table 6

Total Man-Day Effort for 10% Recovery of Various
Size Refineries

(1 man-day = 24 man-hr)

Standard Intensity (r/hr at 1 hr)	Shut-down Time (hr)	Activity	Refinery Size B/D)					
			5000	15,000	40,000	80,000	150,000	250,000
100 300 1000	1	Staging Repair Total	3 70 73	10 260 270	29 800 830	65 1800 1900	130 3600 3700	240 6400 6600
	3	Staging Repair Total	3 40 43	10 140 150	29 430 460	65 950 1000	130 2000 2100	240 3400 3600
	6	Staging Repair Total	3 20 23	10 90 100	29 270 300	65 600 670	130 1200 1300	240 2000 2400
3000 10,000 30,000	1	Decon* Repair Total	15 70 85	63 260 320	180 800 1000	390 1800 2200	810 3600 4400	1400 6400 7800
	3	Decon* Repair Total	15 40 55	63 140 200	180 430 610	390 950 1300	810 2000 2800	1400 3400 4800
	6	Decon* Repair Total	15 20 35	63 90 150	180 270 450	390 600 990	810 1200 2000	1400 2200 3600

* Includes staging-area and vital-area decontamination.

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$$T_A = T_E + T_D + T_R \qquad\qquad (2)$$

where

T_A = time of availability of 100% of resources (days after burst).

T_E = earliest permissible entry time to start decontamination (days after burst).

T_D = time required for radiological reclamation (days).

T_R = time required for repairs (days).

T_A is assumed to be the time at which repairs are completed. The availability of a percentage of the resources, for example, 30%, can be referred to as the "time of partial availability of resources" and can be expressed as:

$$T_A (30) = T_E + T_D + T_R (30) \qquad\qquad (3)$$

In the subsequent formulations, the terms T_E and T_D have been combined as T_{ER} (time when repairs can start), resulting in a simpler formulation with a negligible loss in accuracy.

The parameters (T_E, T_D and T_R) that govern T_A are discussed in 5.3.2 through 5.3.5.

5.3.2 Earliest Entry Time, T_E

The earliest entry time, T_E, is governed by the dose restrictions, the standard intensity, the respective residual numbers prevailing during decontamination and repair, the length of the decontamination work shift, and the total time required for the decontamination. The effect of several of these parameters has been limited by virtue of the assumptions and of the situation considered. For example, the residual number after decontamination, which controls the accumulated dose to repair personnel, has been assumed to be 0.1 for all cases. This assumption also has the effect of setting the limiting dose criteria as 30 r/day (see 2.4). Under the dose restrictions and assumed decontamination effectiveness of this study, the time required for decontamination would not affect the entry time if the decontamination time did not exceed one week; in all cases considered, the decontaminations time was less than one week.

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As a consequence, for a given standard intensity, the two governing parameters for the entry time are the length of the work shift for the decontamination work crew, F_T, and the average residual number prevailing during the decontamination, F_D. When the values of earliest entry time (T_E) vs standard intensity are plotted on log-log paper, the points fall on a straight line, which indicates a relationship of the form:

$$T_E = C' (d_o)^{\alpha'} \tag{4}$$

One such surve is shown in Fig. 21. This curve is for the case where $F_T = 4/24$ and $F_D = 1.0$. The values of the constants, C' and α', for this case were determined empirically from inspection of this curve and are $C' = 0.031$ and $\alpha' = 0.70$. The repair crews work 8 hr per day in the vital-area which has been decontaminated to a residual number, F_D', of 0.1. Values of C' and α' were similarly determined for other values of F_D and F_T and are given in Table 7.

Table 7

Values of C' and α'

F_T	F_D	C'	α'
8/24	1.0	0.050	0.70
4/24	1.0	0.031	0.70
8/24	0.5	0.030	0.70
4/24	0.5	0.020	0.70

5.3.3 Decontamination Time, T_D

The time, T_D, required to decontaminate the vital area of a given oil refinery will depend on the following factors, (1) the mass loading* which increases as the standard intensity, (2) the size of the refinery, which determines the vital area, (3) the characteristics of the surfaces to be decontaminated, (4) the decontamination methods employed. Figure 8 indicates that for a mass loading of 150 g/ft^2, equivalent to a standard intensity of 3000 r/hr, and for a work shift length of 4 hours, the times required to decontaminate a refinery of 3000 B/D or larger would vary from 1-1/2 to 5 days as read from the dashed line; there are very few refineries of less than 3000 B/D production. For an 80,000 B/D refinery it would require 2 days to decontaminate. Because decontamination times cannot be accurately determined, because these times are usually

---

* Surface density of deposited fallout, gms/ft^2.

10^2

T_E (DAYS)

10

1.0

Decontamination crews work 4 hr/day
$F_D = 1.0$
Repair crews work 8 hr/day
$F_D' = 0.1$

10^3 10^4 10^5

STANDARD INTENSITY, d_0 (r/HR AT 1 HR AFTER BURST)
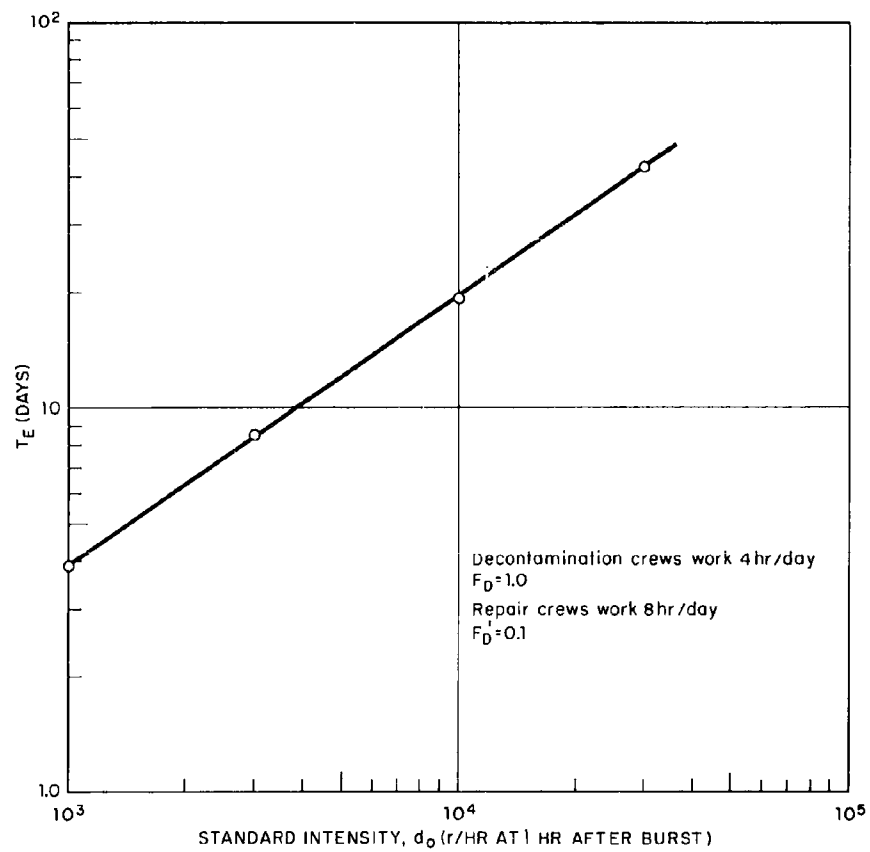
Fig. 21 T_E vs Standard Intensity

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small compared to the repair times, and for the sake of simplification in the empirical formulations which follow, an average time of 2 days has been selected as the time required to decontaminate a refinery with medium mass loading.

Table 8 was prepared to indicate how the decontamination time varies with mass loading. Some experimental data exists--Ref. 5-- which show that the effort and time required to decontaminate a surface to a given level is proportional to the mass loading. Unfortunately, these data are restricted to mass loadings ranging from 10 to 100 g/ft^2; in the situations being considered mass loadings as high as 1,000 g/ft^2 could be encountered corresponding to a standard intensity of 30,000 r/hr. For such high intensities, the decontamination effort and time could have been grossly underestimated. For these reasons, Table 8, which is based on insufficient experimental data, cannot be considered very reliable.

Table 8

Estimated Decontamination Times in Days
(For Refineries Larger Than 10,000 B/D)

Standard Intensity (r/hr)	Length of Work Shift	
	4 hr/day	8 hr/day
300	< 1	< 1
1000	1	< 1
3000	2	1
10,000	3	1-1/2
30,000	4	2

5.3.4 Repair Entry Time, T_{ER}

The time at which repairs can be started, T_{ER}, is the time at which decontamination is completed, that is, $T_E + T_D$. For the problem at hand where the governing dose restriction is 30 r/day, we can determine $T_E + T_D$ by adding the T_E values obtained with Eq. 4 to the T_D values of Table 8. One such curve for the sum of these two times is shown in Fig. 22. This curve also is for the case where $F_T = 4/24$ and $F_D = 1.0$. As can be seen, the values of T_{ER} vs d_o plot as a straight line on log-log paper. This relationship has the form:

$$T_{ER} = T_E + T_D = C(d_o)^\alpha \qquad (5)$$

The values of the constants C and α were determined empirically by inspection of the respective curves for four combinations of F_T and

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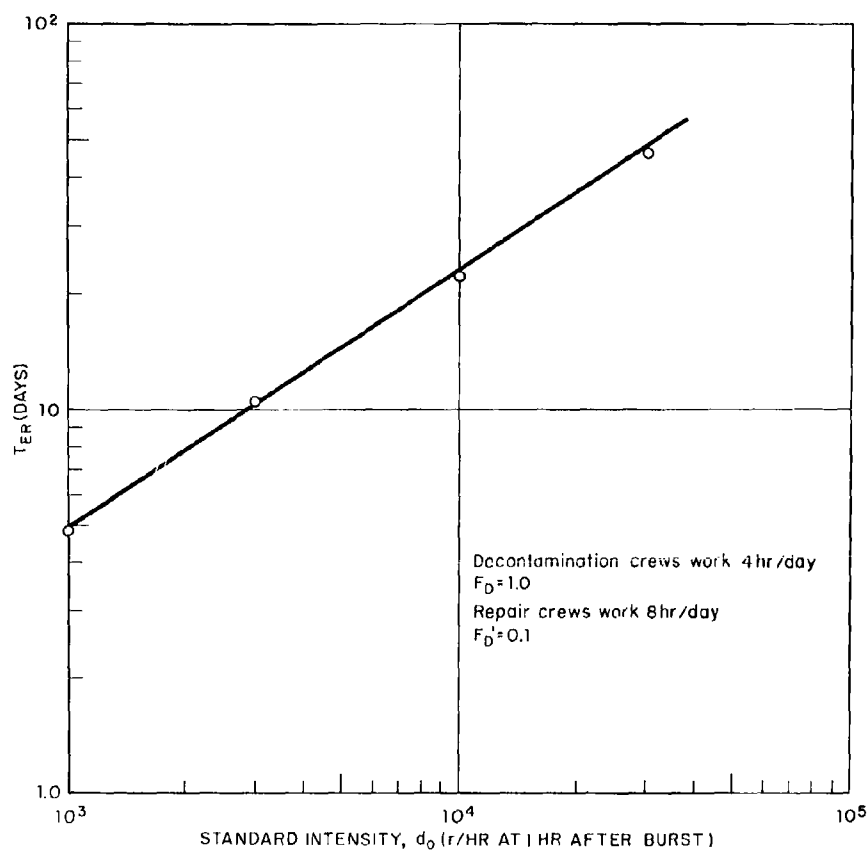
Fig. 22 T_{ER} vs Standard Intensity for F_D = 1.0

F_D values, and are given in Table 9.

Table 9

Values of C and α

F_T	F_D	C	α
8/24	1.0	0.070	0.67
4/24	1.0	0.048	0.67
8/24	0.5	0.043	0.67
4/24	0.5	0.031	0.67

5.3.5 Repair Time, T_R

The time required to achieve partial or complete repairs, T_R, depends on the length of the work shift and the size of the work force participating in the repairs, and the extent of the repairs required which in turn depends on the refinery size and shutdown time; Eq. 1 of 4.3 has been used to compute T_R.

Repair man-days vs refinery size for various degrees of production capacity plot as straight lines on log-log paper as shown earlier in Figs. 15, 16, and 17. This relationship is of the form:

$$E_R = PS^p \tag{6}$$

where

E_R = average repair effort in man days. (1 man-day = 24 man-hr)

S = size of refinery in B/D

P, p = constants that depend on shutdown time and percent production capacity.

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The two constants, P and p, have been determined empirically from Figs. 15, 16, and 17 and have been tabulated in Table 10. Similarly, from Fig. 5, the relationship between the total number of employees $\underline{vs}$ refinery size is of the form

$$N = KS^k \qquad (7)$$

Table 10

Values of Constants P and p

% Normal Production	Shutdown Time in hours	P	p
100	1 3 6	3.02×10^{-6} 1.66×10^{-6} 1.09×10^{-6}	1.96 " "
30	1 3 6	9.50×10^{-5} 5.00×10^{-5} 3.10×10^{-5}	1.58 " "
10	1 3 6	4.47×10^{-3} 2.40×10^{-3} 1.50×10^{-3}	1.14 " "

where N = total number of employees, S = refinery size in B/D, K = 0.0023, and k = 1.15.

The number of workers per shift is

$$N_s = F_T' \ F_N' \ KS^k \qquad (8)$$

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where

F_T' = fraction of day worked by each repair shift, which may have any value between 4/24 and 8/24.

F_N' = fraction of total employees of a refinery participating in repairs, which was assumed to be 0.75.

Finally, the repair time in days, T_R, is given by

$$T_R = \frac{E_R}{N_s} = \frac{P}{F_T' \ F_N' \ K} S^{(p-k)}$$ (9)

which can be simplified to

$$T_R = \frac{435 \ P}{F_T' \ F_N'} S^{(p-1.15)}$$ (10)

5.3.6 Equation for Time of Availability of Resources, T_A

By appropriate substitution of Eqs. 5 and 10, Eq. 2 can now be expressed in a form suitable for general computation as follows:

$$T_A = Cd_o^{0.67} + \frac{435 \ P}{F_T' \ F_N'} S^{(p-1.15)}$$ (11)

Equation 11 is applicable under the following set of conditions:

(1) Dose restrictions of 30 r/day, 230 r/2 wk., and 1000 r/yr.

(2) The decontamination crews work from 4 to 8 hr per shift until decontamination is completed (F_T).

(3) The decontamination crew receives from 0.5 to 1.0 of the free-field dose during work hours (F_D).

(4) Repair crews work from 4 to 12 hr per day, 7 days per wk (F_T').

(5) Repair crews receive 0.1 of the free-field dose during repairs (F_D').

(6) Personnel receive negligible doses prior to earliest entry time and during nonwork hours.

Equation 11 is not valid for standard intensities of less than 1000 r/hr and for refinery sizes smaller than 10,000 B/D. These special cases are treated in 5.4.1.

5.4 PROCEDURE FOR COMPUTING T_{ER}, T_R, AND T_A

In the preceding subsections, an empirical equation was developed for computing the time of availability of resources as the sum of two times--one, T_{ER}, depending primarily on the standard intensity of the radiation field, and the other, T_R, which gives the time for repairs, depending primarily on the size of the refinery. In this section, the procedure for computing T_A for any value of standard intensity and for a refinery of any size is described.

5.4.1 Special Cases

Equation 11 is directly applicable to refineries equal to and larger than 10,000 B/D and to standard intensities equal to or exceeding 1,000 r/hr. The pattern for smaller refineries departed somewhat from the pattern discernible for the larger refineries; and for lower values of standard intensity, decontamination was not required to satisfy the dose restrictions. As a consequence, these smaller-refinery, lower-standard intensity cases are treated separately here. Table 11 presents best estimates for these special cases based on available data. The tabulated values are used in conjunction with Eqs. 5 and 10 to give estimates of the times of availibility of resources for these cases. Specific directions on how to perform the computations are given below.

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Table 11

Times of Availability of Resources in Days for Special Cases*

Standard Intensity (r/hr at 1 hr)	Activity	Shutdown Time in Hours		
		1	3	6
100 to 300	T_E	< 1	< 1	< 1
	T_D	< 1	< 1	< 1
	T_R	7	4	2
	T_A	8	5	3
300 to 1,000	T_E	< 2	< 2	< 2
	T_D	< 1	< 1	< 1
	T_R	7	4	2
	T_A	9	6	4

* The times of availability for resources in this table are for cases where refinery sizes are less than 10,000 B/D and standard intensities are less than 1,000 r/hr.

5.4.2 Summary Chart for Computations of T_A

Figure 23 presents diagrammatically the range of standard intensities, d_o, and refinery sizes, S. This figure is divided into four regions, each of which requires a slightly different computational procedure to obtain the times of availability of resources. Because of simplifications in the formulation, there will be discontinuities in the calculations of T_A, particularly along the boundary separating Regions I and III, and II - IV. It is suggested that when this occurs, T_R be obtained by the methods of Regions III and IV. Some pertinent, explanatory notes in the use of Fig. 23 are summarized below.

Figure 23

Summary Chart for Computations of Time of Availability, T_A
d_o (standard intensity in r/hr)

	100	1000	30,000
3000	**I**	**II**	
	Special Cases	$T_A = C \ (d_o)^{\alpha} + T_R$	
	Use Table 11	Use Eq. 5 for $C \ (d_o)^{\alpha}$	
10,000	directly	and read T_R values from Table 11	
	III	**IV**	
	$T_A = 3 \ days + \dfrac{435 \ P}{F_T^, F_N^,} \ S^{(p-1.15)}$	$T_A = C \ (d_o)^{\alpha} + \dfrac{435 \ P}{F_T^, F_N^,} \ S^{(p-1.15)}$	
300,000	For second term, use Eq. 10	Use Eq. 11	

S(refinery size in B/D)
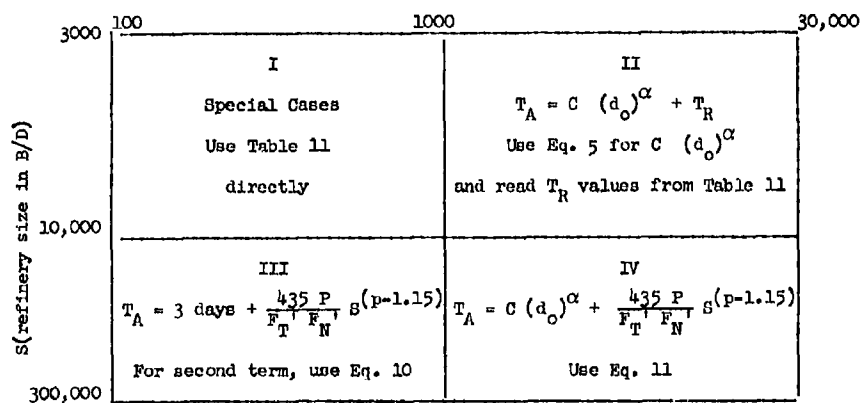
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REGION I: $3,000 < S < 10,000$ B/D; $100 \leq d_o < 1000$ r/hr.
Read the values directly from Table 11.

REGION II: $3,000 \leq S < 10,000$ B/D; $1,000 \leq d_o \leq 30,000$ r/hr

$$T_A = C \; d_o^{\alpha} + T_R$$

Compute the first term, $C \; d_o^{\alpha}$ with Eq. 5 of 5.3.4; selecting appropriate values of C and α from Table 9; read values of T_R from Table 11. The values of T_R to be used in REGION II range from 2 days to 7 days and are applicable to three percentages of production capacity - 10%, 30%, and 100%.

REGION III: $10,000 < S \leq 300,000$ B/D; $100 < d_o < 1,000$ r/hr.
For these values of standard intensities, the sum, $T_E + T_D$, ranges from 1 to 4 days. An intermediate value of 3 days can be selected without introducing a significant error in T_A. Calculate T_A using the following formula

$$T_A = 3 \text{ days} + \frac{435 \; P}{F_T \, ' \, F_N \, '} S^{(p-1.15)}$$

where the last term is Eq. 10 of 5.3.5.

REGION IV: $10,000 < S < 300,000$ B/D; $1000 \leq d_o \leq 30,000$ r/hr.
Use Eq. 11 of paragraph 5.3.6.

5.5 ILLUSTRATIVE EXAMPLE OF COMPUTATIONS

In this section a specific case will be considered. This example has been included to show in detail the computations involved in obtaining the times of availability of resources as obtained from Eq. 11. In addition, the results for this one case have been tabulated so that the reader can form an idea of the magnitudes of the times involved in the recovery of petroleum refineries for an intermediate situation, i.e., one in which the estimated times of availability of resources lies somewhere in the middle of the range of the possible extreme values. In this example the values of the pertinent parameters are:

Decontamination Crew: $F_D = 1.0$ $F_T = 4/24$

Repair Crew: $F_D' = 0.1$ $F_T' = 8/24$

The dose restrictions are those specified: 30 r/day; 230 r/2 wks, and 1000 r/yr and the doses accumulated by the recovery personnel do not exceed these restrictions. The fraction of the total work force of the refinery participating in the repair is 75%, i.e., $F_N' = 0.75$.

5.5.1 Details of Computations

To clarify the computations involved, a specific case has been selected. This is the case for 100% recovery, 1-hr shutdown time, 3,000 r/hr at 1 hr standard intensity, and a refinery size of 80,000 B/D. The formula for the time of availability is Eq. 11 which is repeated below

$$T_A = C d_o^{0.67} + \frac{435\ P}{F_T'\ F_N'}\ S^{(p-1.15)}$$

It will be recalled that the first term on the right gives the sum of two terms - earliest entry time plus time required for decontamination; the second term gives the time required for repairs. The total time of availability in days is the sum of these two terms. The computations follow.

Step 1: Evaluating first term $T_{ER} = (T_E + T_D)$.

From Table 9, for a value of $F_D = 1.0$ and $F_T = 4/24$, $C = 0.048$ and $\alpha = 0.67$. Substituting the values for C, α and d_o in the first term one obtains

$$T_{ER} = (0.048)\ (3,000)^{0.67} = 10\ \text{days}$$

Step 2: Evaluating the second term (T_R)

Substitute $F_T' = 8/24$, $F_N' = 0.75$, S = 80,000 B/D, and the applicable values of P and p from Table 10, i.e., $P = 3.02 \times 10^{-6}$ and $p = 1.96$.

Hence,

$$T_R = \frac{(435)\ (3.02 \times 10^{-6})}{(8/24)\ (0.75)}\ .(80,000)^{(1.96 - 1.15)} = 49\ \text{days}.$$

<u>Step 3</u>:   Summing values of Steps 1 and 2 gives

$$T_A \, (100) = 10 + 49 = 59 \text{ days}.$$

This is the answer desired.

The doses accumulated by the working force are within the specified dose restrictions.

5.5.2 <u>Results for Intermediate Case</u>

For the intermediate case under consideration, values for T_{ER}, T_R, and T_A have been similarly computed for all values of the parameters. They are shown in Tables 12 through 18. It will be recalled that the formula are applicable only to refineries equal to and larger than 10,000 B/D and for values of standard intensities equal to and larger than 1000 r/hr.

Values of time for the special cases have been obtained directly from Table 11.

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Table 12

Time in Days for 100% Recovery: 1-Hour Shutdown Time

Standard Intensity (r/hr at 1 hr)	Time of Interest	Refinery Size (B/D)					
		5000	15,000	40,000	80,000	150,000	250,000
100	T_{ER}	1	1	1	1	1	1
	T_R	7	13	28	49	82	124
	T_A	8	14	29	50	83	125
300	T_{ER}	2	2	2	2	2	2
	T_R	7	13	28	49	82	124
	T_A	9	15	30	51	84	126
1000	T_{ER}	5	5	5	5	5	5
	T_R	7	13	28	49	82	124
	T_A	12	18	33	54	87	129
3000	T_{ER}	10	10	10	10	10	10
	T_R	7	13	28	49	82	124
	T_A	17	23	38	59	92	134
10,000	T_{ER}	22	22	22	22	22	22
	T_R	7	13	28	49	82	124
	T_A	29	35	50	71	104	146
30,000	T_{ER}	46	46	46	46	46	46
	T_R	7	13	28	49	82	124
	T_A	53	59	74	95	128	170

Table 13

Time in Days for 100% Recovery: 3-Hour Shutdown Time

Standard Intensity (r/hr at 1 hr)	Time of Interest	Refinery Size (B/D)					
		5000	15,000	40,000	80,000	150,000	250,000
100	T_{ER}	1	1	1	1	1	1
	T_R	4	7	15	27	45	67
	T_A	5	8	16	28	46	68
300	T_{ER}	2	2	2	2	2	2
	T_R	4	7	15	27	45	67
	T_A	6	9	17	29	47	69
1000	T_{ER}	5	5	5	5	5	5
	T_R	4	7	15	27	45	67
	T_A	9	12	20	32	50	72
3000	T_{ER}	10	10	10	10	10	10
	T_R	4	7	15	27	45	67
	T_A	14	17	25	37	55	77
10,000	T_{ER}	22	22	22	22	22	22
	T_R	4	7	15	27	45	67
	T_A	26	29	37	49	67	89
30,000	T_{ER}	46	46	46	46	46	46
	T_R	4	7	15	27	45	67
	T_A	50	53	61	73	91	113

Table 14

Time in Days for 100% Recovery: 6-Hour Shutdown Time

Standard Intensity (r/hr at 1 hr)	Time of Interest	Refinery Size (B/D)					
		5000	15,000	40,000	80,000	150,000	250,000
100	T_{ER}	1	1	1	1	1	1
	T_R	2	5	10	18	30	45
	T_A	3	6	11	19	31	46
300	T_{ER}	2	2	2	2	2	2
	T_R	2	5	10	18	30	45
	T_A	4	7	12	20	32	47
1000	T_{ER}	5	5	5	5	5	5
	T_R	2	5	10	18	30	45
	T_A	7	10	15	23	35	50
3000	T_{ER}	10	10	10	10	10	10
	T_R	2	5	10	18	30	45
	T_A	12	15	20	28	40	55
10,000	T_{ER}	22	22	22	22	22	22
	T_R	2	5	10	18	30	45
	T_A	24	27	32	40	52	67
30,000	T_{ER}	46	46	46	46	46	46
	T_R	2	5	10	18	30	45
	T_A	48	51	56	64	76	91

Table 15

Time in Days for 30% Recovery: 1-Hour Shutdown Time

Standard Intensity (r/hr at 1 hr)	Time of Interest	Refinery Size (B/D)					
		5000	15,000	40,000	80,000	150,000	250,000
100	T_{ER}	1	1	1	1	1	1
	T_R	7	10	16	21	28	35
	T_A	8	11	17	22	29	36
300	T_{ER}	2	2	2	2	2	2
	T_R	7	10	16	21	28	35
	T_A	9	12	18	23	30	37
1000	T_{ER}	5	5	5	5	5	5
	T_R	7	10	16	21	28	35
	T_A	12	15	21	26	33	40
3000	T_{ER}	10	10	10	10	10	10
	T_R	7	10	16	21	28	35
	T_A	17	20	26	31	38	45
10,000	T_{ER}	22	22	22	22	22	22
	T_R	7	10	16	21	28	35
	T_A	29	32	38	43	50	57
30,000	T_{ER}	46	46	46	46	46	46
	T_R	7	10	16	21	28	35
	T_A	53	56	62	67	74	81

Table 16

Time in Days for 30% Recovery: 3-Hour Shutdown Time

Standard Intensity (r/hr at 1 hr)	Time in Interest	Refinery Size (B/D)					
		5000	15,000	40,000	80,000	150,000	250,000
100	T_{ER}	1	1	1	1	1	1
	T_R	4	5	8	11	15	18
	T_A	5	6	9	12	16	19
300	T_{ER}	2	2	2	2	2	2
	T_R	4	5	8	11	15	18
	T_A	6	7	10	13	17	20
1000	T_{ER}	5	5	5	5	5	5
	T_R	4	5	8	11	15	18
	T_A	9	10	13	16	20	23
3000	T_{ER}	10	10	10	10	10	10
	T_R	4	5	8	11	15	18
	T_A	14	15	18	21	25	28
10,000	T_{ER}	22	22	22	22	22	22
	T_R	4	5	8	11	15	18
	T_A	26	27	30	33	37	40
30,000	T_{ER}	46	46	46	46	46	46
	T_R	4	5	8	11	15	18
	T_A	50	51	54	57	61	64

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Table 17

Time in Days for 30% Recovery: 6-Hour Shutdown Time

Standard Intensity (r/hr at 1 hr)	Time in Interest	Refinery Size (B/D)					
		5000	15,000	40,000	80,000	150,000	250,000
100	T_{ER}	1	1	1	1	1	1
	T_R	2	3	5	7	9	11
	T_A	3	4	6	8	10	12
300	T_{ER}	2	2	2	2	2	2
	T_R	2	3	5	7	9	11
	T_A	4	5	7	9	11	13
1000	T_{ER}	5	5	5	5	5	5
	T_R	2	3	5	7	9	11
	T_A	7	8	10	12	14	16
3000	T_{ER}	10	10	10	10	10	10
	T_R	2	3	5	7	9	11
	T_A	12	13	15	17	19	21
10,000	T_{ER}	22	22	22	22	22	22
	T_R	2	3	5	7	9	11
	T_A	24	25	27	29	31	33
30,000	T_{ER}	46	46	46	46	46	46
	T_R	2	3	5	7	9	11
	T_A	48	49	51	53	55	57

Table 18

Time in Days for 10% Recovery of Any Size Refinery:
for Three Shutdown Times

Standard Intensity (r/hr at 1 hr)	Time of Interest	Shutdown Time, hours		
		1	3	6
100	T_{ER}	1	1	1
	T_R	7	4	2
	T_A	8	5	3
300	T_{ER}	2	2	2
	T_R	7	4	2
	T_A	9	6	4
1000	T_{ER}	5	5	5
	T_R	7	4	2
	T_A	12	9	7
3000	T_{ER}	10	10	10
	T_R	7	4	2
	T_A	17	14	12
10,000	T_{ER}	22	22	22
	T_R	7	4	2
	T_A	29	26	24
30,000	T_{ER}	46	46	46
	T_R	7	4	2
	T_A	53	50	48

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SECTION 6

RADIOLOGICAL HISTORY OF RECOVERY PERSONNEL

6.1 GENERAL

In this section the radiological dose history of the recovery personnel will be discussed. This requires determining the earliest entry times into the radiation field and in computing accumulated doses during the subsequent recovery. It will be recalled that the dose restrictions under which recovery is to be performed state that the doses accumulated by personnel should not exceed 30 r/day, 230 r for any two week period, or 1000 r for a year. The schedules for the recovery as summarized in Section 5 meet these restrictions. In the discussion that follows, the methods by which the doses were computed are briefly described, and the doses accumulated for one specific set of the values of the controlling parameters are tabulated for illustrative purposes. This example is typical of all acceptable recovery schedules covered in Section 5 in that the dose restrictions of the problem are not exceeded.

The computations were made in accordance with the methods described fully in Ref. 1. In particular, the concepts of dose multiplier of Table 3.2 and the accumulated doses of Table 3.9 of the above reference were employed. In Appendix E, dose-history calculations are shown in more detail for the case where the dose restrictions are a maximum of 230 r for a 2-wk period and 1000 r for a 1-yr period.

6.2 SITUATION CONSIDERED

As previously pointed out, the dose history of the recovery personnel does not depend on the characteristics of the refineries. In the recovery schedules, recovery is conducted by a given fraction of the total work force--namely, 75% in the analysis. The same people perform the decontamination and the repairs, and later conduct the refinery operations. It is assumed that, after the fallout event is over and after a suitable delay, refinery personnel return to the refinery and have accumulated a negligible dose. They work 4 hours per day during the decontamination phase; the times required to decontaminate are those

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shown in Table 8. During repairs, they work 8 hours per day. During off hours they retreat to a staging area where the radiation field is markedly less intense than that in the surrounding area. The parameters on which the dose history will depend are listed below; values that will be used in the illustrative example which follows are shown where applicable:

d_o = standard intensity (from 100 r/hr to 30,000 r/hr)

F_T = fraction of day (24 hr) worked by decontamination crew (4/24)

F_D = average residual number prevailing during decontamination phase (0.5)

F_T' = fraction of day (24 hr) worked by repair crew (8/24)

F_D' = residual number achieved in vital area by decontamination (0.1)

F_{SA} = residual number of staging area (0.004)

6.3 EARLIEST ENTRY TIMES

Figure 24 shows the earliest entry times permissible for the above set of values. If entry were earlier, the recovery personnel would receive a dose larger than the 30 r allowed for the first day. For the assumed decontamination effectiveness, the 30-r/day dose restriction is controlling. For the lower values of d_o (from 100 to 1000 r/hr), the dose restrictions of 230 r for 2-wk and 1000 r for 1-yr will be satisfied even if the vital area is not decontaminated; for the higher values of d_o, these two restrictions are not exceeded if the vital area is decontaminated.

6.4 ACCUMULATED DOSES OF PERSONNEL

To verify that the dose restrictions have not been exceeded, the doses accumulated during the first two weeks after entry and during the first year after entry are calculated. Table 19 shows the doses accumulated by the recovery personnel during work hours; Table 20, during nonwork hours when they remain in the staging area; and Table 21 shows the sum of these doses. These values are for the case described in 6.2. As can be seen for this case, the 2-wk and 1-yr dose restrictions have not been exceeded. Computations show that the dose

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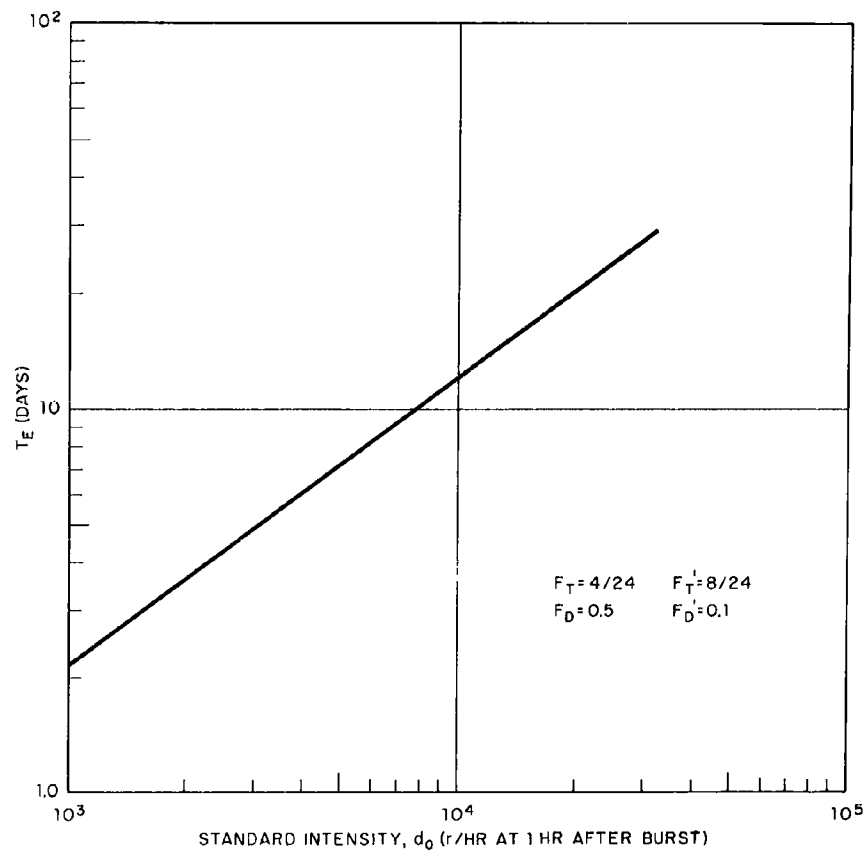
Fig. 24 T_E vs Standard Intensity for F_D = 0.5

accumulated during the first two weeks of occupancy exceeds that for any other subsequent two week period. It is to be noted that the magnitudes of the doses accumulated in the staging area are small compared to those during work hours. For simplicity in calculations, the doses accumulated in the staging area may often be neglected.

The case considered is typical of all other possible solutions covered in Section 5 in that the dose restrictions of the problem are not exceeded.

Table 19

Doses Accumulated During Working Hours

d_o (r/hr)	T_E (days)	2-wk Dose (r)	1-yr Dose (r)
100*	< 1	< 10	88
300*	< 1	< 15	245
1,000	1.8	64	125
3,000	5.3	94	211
10,000	11.5	137	368
30,000	26.5	172	600

* No decontamination of vital areas; only staging area is necessary.

Table 20

Doses Accumulated During Nonwork Hours

d_o (r/hr)	T_E (days)	2-wk Dose (r)	1-yr Dose (r)
100	< 1	< 1	< 2
300	< 1	< 2	< 3
1,000	1.8	5	11
3,000	5.3	7	19
10,000	11.5	10	33
30,000	26.5	12	52

Table 21

Total Dose Accumulated

d_o (r/hr)	T_E (days)	2-wk Dose (r)	1-yr Dose (r)
100	< 1	~ 11	~ 90
300	< 1	~ 17	~ 250
1,000	1.8	69	136
3,000	5.3	101	230
10,000	11.5	147	401
30,000	26.5	184	652

SECTION 7

RECOMMENDATIONS

The second objective of this study was to recommend measures that
could be taken to alleviate the effects of a contaminating nuclear
attack of the type considered and expedite the recovery (decontamination
and repairs) of petroleum refineries. Such recommendations are listed
below. (Many of them are applicable to other industrial plants.)

1. General Survival Plan. A few refineries have a general
survival plan; most of them do not. If an attack were to occur in the
near future, one could not at present visualize personnel of these
refineries surviving or making a concentrated effort to save their
plant. One can foresee only chaos and wild flight, with abandonment
of the operating plant.

If a serious effort is contemplated for the protection of personnel
and the recovery of refineries, it is recommended that a survey be made
in each refinery to evaluate the effectiveness of certain buildings as
fallout shelters. In the medium-sized to large-sized refineries, there
usually are many concrete and brick buildings that could be modified
to provide adequate protection. In addition, a study should be made of
evacuation possibilities. The thought here is that a small group would
remain in the refinery to shutdown the plant before the arrival of
fallout and then go to shelters near their work locations. This
measure would preclude abandonment of the operating refinery and its
resulting complete loss, and would tend to minimize fast shutdown
damage and the subsequent repairs that would be required. If feasible,
the other personnel would evacuate the refinery and the potential fallout
area before fallout arrival.

In drawing a general survival plan, it is recommended that
refineries located near large bodies of navigable water investigate the
possibility of using ships for both evacuation and shelter. The
radiation intensities aboard a ship in contaminated water would be
much less than those on contaminated land because of the settling and
dispersion of radioactive fallout in the water, the attenuation of

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radiation by the water, and the shielding provided by the ship's structure. Also, the ships could serve as adequate staging areas for decontamination and repair work, and the water would offer a much less hazardous means of traveling to and from the refinery.

2. **Nucleus of a Recovery Force.** In England and Germany during World War II, a central group of personnel was trained to initiate recovery of bombed plants and was sent to bombed plants as the need arose. This practice proved successful. In case of nuclear attack, refinery personnel may not be depended on to cope wholeheartedly and efficiently with the recovery and resumption of operations of the plant because of more pressing personal problems. Training and use of such a group for recovery would prove particularly effective in speeding up recovery.

3. **Training of Plant Personnel.** Most of the personnel in refineries have only a general familiarity with the characteristics of radioactive fallout, the hazards and biological effects of ionizing radiations, and the countermeasures that can be taken to reduce radiation hazards. In order that refinery personnel may be able to carry out the necessary countermeasures effectively, they should undergo a period of instruction and training in the fundamentals of the above subjects. At least, key personnel should undergo such instruction and training so that they can initiate protective measures and direct the recovery operations.

4. **Emergency Shutdown Study and Personnel Drills.** Because of the large repair effort that may be required as a result of fast emergency shutdown, it is recommended that a study be made to determine the optimum procedure for carrying out fast emergency shutdown of various types of refinery, and that personnel be instructed and drilled in such procedure.

5. **Radiological Reclamation of Industrial Complexes.** Existing data on radiological reclamation are based on tests conducted in relatively simple areas, such as paved open spaces and uncomplicated residential mock ups; these data include the determination of methods and procedures for reclamation, the estimation of logistic requirements and rates of performance, and the evaluation of the effectiveness and overall reduction of intensity of reclamation techniques. Industrial sites, such as one encounters in a petroleum refinery, present a much more difficult and complex problem. One cannot extrapolate from currently available data to industrial sites of this type and have any confidence in the results. To obtain data that can be used with an acceptable degree of confidence, it is recommended that reclamation

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tests of the type indicated above be conducted on various types of industrial sites.

6. Preparation of Refinery Grounds. In many of the refineries visited, the task of decontaminating the vital areas would be very difficult because of the type of existing surfaces. Certain such surfaces could be easily improved. For instance, in new paving or in resurfacing use of a slightly different method of paving would result in a surface that would considerably simplify decontamination.

7. Availability of Critical Equipment and Repair Materials. A study conducted by the U.S. Air Force/ indicates that obtaining certain critical refinery equipment and repair materials could result in long delays of the order of 9 to 27 months. To expedite recovery of refineries, it is recommended that consideration be given to a faster means of obtaining critical equipment and materials than that indicated in Ref. 7.

8. Vulnerability and Repairs of Large and Small Refineries. The analysis contained in Appendix F reveals that large refineries are much more vulnerable to fast shutdown times than smaller refineries. In case of an expected attack and if a choice is needed and possible, it is recommended that the larger refineries be shut down in advance of the attack and the smaller refineries be allowed to continue operations. In addition, if a group of refineries were damaged due to a fallout event of the type considered in this study and if the shut-down times are known to be approximately the same, recovery of the smaller refineries should be performed first, other factors being equal.

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APPENDIX A

BASIC CONCEPTS OF FALLOUT FROM THERMONUCLEAR WEAPONS

The purpose of this appendix is to present a brief, nontechnical
synopsis of the problems created by the detonation of a thermonuclear
weapon, with particular emphasis on fallout phenomena. This appendix
is oriented primarily to personnel unfamiliar with the fundamentals of
radioactive fallout and radiological countermeasures. Discussed here
are characteristics of fallout, methods of measuring radiation,
determination of dosage,effects of radiation on personnel, and counter-
measures against radiation. References and other readily available
literature of general interest are listed at the end of this appendix.

A.1 OVERALL EFFECTS[A.1, A.2]

The detonation of a thermonuclear weapon results in the release of
a tremendous amount of energy in a very short time. A weapon of 10
megatons (MT) releases energy equivalent to the detonation of 10 million
tons of TNT. This energy appears as light, heat (thermal radiation),
air blast, and ionizing radiation. A weapon may be detonated above,
on, or below either land or water; but we shall examine the case most
applicable to industrial targets: a low-altitude surface burst
detonated above land.

At the point of detonation, called ground zero (GZ), the fireball,
which has a temperature of several million degrees, vaporizes the
immediate surroundings, forming a large shallow crater -- over a half
mile in diameter for a 20-MT burst. For the 20-MT case, the destructive
blast effects (5 psi) will extend radially to about 8 miles from GZ.
Moderately severe thermal effects, capable of producing second-degree
burns of skin or of igniting trash fires, will occur radially to about
32 miles from GZ. Initial radiation (that occurring in about the first
minute after burst), although consisting of both gamma rays and neutrons,
is not biologically hazardous beyond a radius of about 3-1/2 miles.
Following the burst, there is a secondary hazard: residual fallout
radiation, which can deliver lethal radiation doses for hundreds of
miles downwind from GZ. When a nuclear weapon is detonated on or near
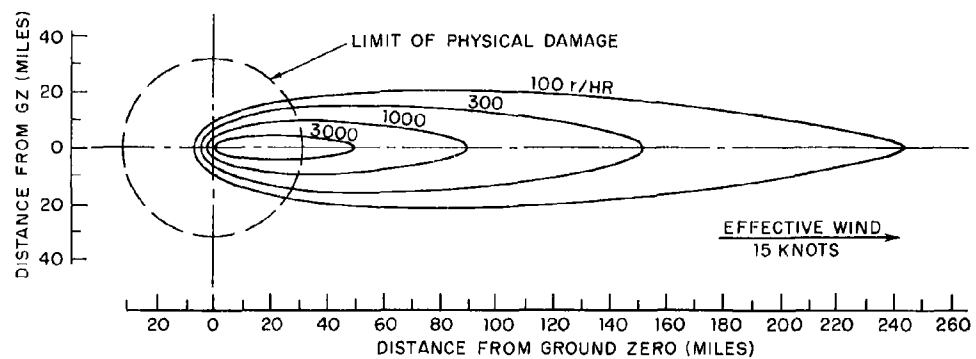
Fig. A.1 Idealized 1-Hr Dose-Rate Contours for a 20-MT Surface Burst

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the ground surface, large masses of vaporized and pulverized debris
are sucked upward by the hot rising fireball to a height of 100,000 ft
or more, forming the familiar mushroom cloud. Radioactive fission
products condense on the small debris particles and are subsequently
carried back to the earth as dust. This dust is termed fallout. Many
of the particles thus formed are heavy enough to descend rapidly while
still intensely radioactive. The result is a relatively close-in area
of extreme radioactive contamination and more distant areas of lesser
hazard.

An idealized case for a single detonation in which it is assumed
that all fallout reaches the ground by 1 hour after the burst, is shown
in Fig. A.1. The approximate limit of physical damage, for this case
fires ignited by thermal radiation, is shown by the dashed circle.
The area covered by radioactive fallout far exceeds the area of physical
damage. Dose-rate contours (lines connecting points of equal dose rate)
are not shown for 10,000 and 30,000 r/hr* because these areas would
normally be within the region of physical damage. However, coincidental
fallout from more than one detonation, or unusual meteorological
conditions, could produce these very high intensities beyond the area
of physical damage.

In actuality, all the fallout does not reach the ground simultane-
ously but rather over a period of hours, depending on downwind distance.
A more useful criterion of fallout hazard is given in Fig. A.2 which
shows the estimated time of arrival of fallout and the total dose to
personnel during a 24-hour period. For example, at a downwind distance
of 80 miles, fallout would begin arriving at about 5 hours and continue
for several hours. A person in the open at this location would receive
a dose of about 3000 roentgens in 24 hours (the first 5 hours of which
would be without exposure). Continued occupancy of the area beyond
24 hours would further increase the total dose.

A.2 CHARACTERISTICS OF FALLOUT

The physical appearance of sizes of fallout particles from a land
surface burst can be likened to that of sand, varying from a coarse
sand (700 microns in diameter) at close-in points to a very fine sand
(50 microns) at distant points. The quantity of fallout per unit area
can be related to radiation intensity rather grossly as follows:

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* The unit of radiation intensity (dose rate) is the roentgen/hour
(r/hr); the unit of dose (dose rate x time) is the roentgen (r).
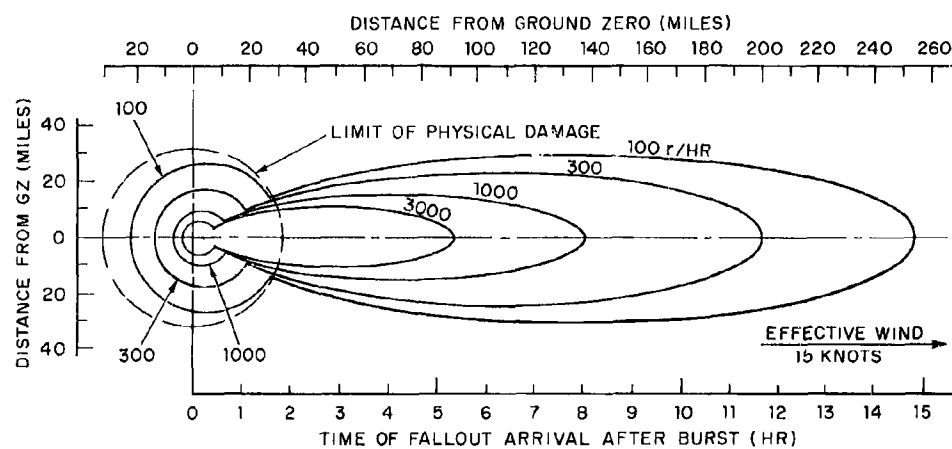
Fig. A.2 Idealized 24-Hr Dose Contours for a 20-MT Surface Burst

Standard Intensity (r/hr at 1 hr)	Initial mass (grams/sq ft)	Thickness of Deposited Fallout (Inches)
100	3	0.001
300	10	0.003
1,000	33	0.01
3,000	100	0.03
10,000	330	0.08
30,000	990	0.25

Fallout, like dust, will accumulate on any horizontal surface and, like dust, is most readily removed from smooth surfaces. However, fallout is unlike dust in that it contains fission products that emit ionizing radiation. Fission products, by the slow release of such radiations produce a wide spectrum of gamma rays and beta particles as a function of time after burst. These particles decay in a characteristic manner, as shown in Fig. A.3. Decay is very rapid at early times, but soon levels off. If we integrate the area under the curve between two times, we obtain the dose for the staytime (cross-hatched area). Several decay rates have been proposed; these are discussed in detail in Appendix D. Table A.1 lists dose multipliers that can be used to determine the dose to personnel in the open. As an example, consider the dose to a person entering an area at 1 day (24 hours) after burst and leaving it 7 days after burst. Letting the standard intensity equal 100 r/hr at 1 hr, the dose to the individual would be computed as follows:

> Dose multiplier, 7th day   2.9
>
> Dose multiplier, 1st day   1.5
>
>   Difference   1.4
>
> Dose = 100 r/hr x 1.4 = 140 r.

The radiation from fallout is not detected by any of the five senses, but instruments can detect and measure it. These instruments, called radiacs, are of two basic types: dose-rate meters and dosimeters. Dose-rate meters, having complex amplifying circuits, measure the
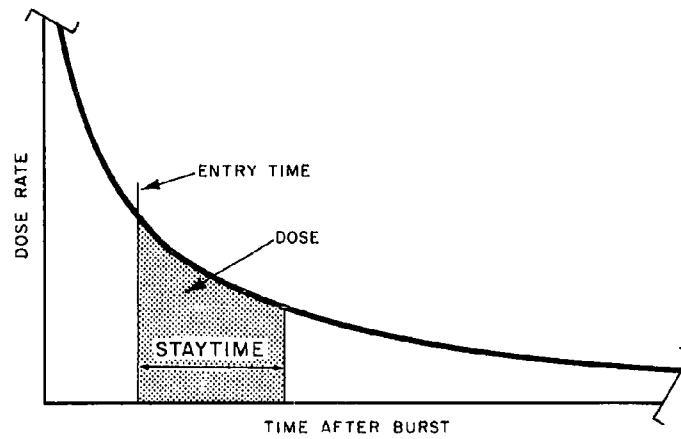
Fig. A.3 Decay Curve for Fallout and Stay Time Dose

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Table A.1

Dose Multipliers

(From Table 3.2 of Ref. A.4)

Time After Burst (Days)*	Dose** Multiplier	Time After Burst (Days)	Dose** Multiplier
1	1.5	2 weeks	3.24
2	2.0	3 weeks	3.38
3	2.3	4 weeks	3.47
4	2.5	1 month	3.49
5	2.7	5 weeks	3.53
6	2.8	6 weeks	3.58
7	2.9	2 months	3.66
8	3.0	9 weeks	3.68
9	3.05	3 months	3.74
10	3.10	4 months	3.79
11	3.15	6 months	3.85
12	3.20	9 months	3.90
13	3.22	1 year	3.91

* 1 Day = 24 hr.

** Dose multiplier times standard intensity gives estimate of dose
to personnel in open from time of burst to time indicated. The
difference between two dose multipliers times the standard intensity
gives an estimate of the dose to personnel in the open between
the two times indicated.

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intensity of the radiation in r/hr. Such meters, a number of which are available (described in Ref. A.3b), are used by monitoring personnel to determine the extent and levels of the radioactive contamination.* The latter information is used to control dosage to the recovery personnel, who must work in the contaminated area for prolonged periods.

Dosimeters are worn by recovery personnel to measure the total doses they accumulate while working in the radiation field. Film badges are the standard dosimeters for obtaining accurate total dose, but "pencil" (or pocket) dosimeters may be used for rapid estimation of dose. Records must be kept of each person's accumulated dose to prevent his dosage from exceeding the prescribed limits.

A.3 EFFECTS OF IONIZING RADIATION

The radiation emitted by deposited fallout will not cause physical damage to stocks or equipment. Such items can become hazardous only by becoming contaminated with fallout. For example, an open cooling pond might be seriously contaminated by fallout settling in it. Closed tanks and systems should be unaffected by fallout.

Human beings, however, are sensitive to ionizing radiations at relatively low contamination levels through several routes. A person can be irradiated externally by gamma rays while standing in a fallout radiation field; or he can be irradiated internally as a result of taking fallout into his body by inhalation, by ingestion of contaminated food or water, or through a break in the skin. For practical purposes, it is sufficient for one to protect himself against the inhalation or ingestion of fallout in the same manner one protects against the inhalation or ingestion of dust. External irradiation by gamma rays, however, presents a more difficult problem. Listed in Table A.2 are the expected effects of acute whole-body irradiation by an external gamma-radiation field. Fortunately, the body has a recuperative capacity, so that the effects are mitigated by receiving the exposure over a period of time. Thus, a 1000-r dose would be fatal if received over a period of a few days, whereas the same dose received over a period of a year would not.

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* The fallout or radiation field can be expected to be fairly uniform, on the average, over a given plant area, but local "hot-spots" may occur where fallout has accumulated. It is the task of the monitoring teams to evaluate both the general fallout pattern and to locate any "hot-spot" problem areas.

Table A.2

Biological Effects of Acute and
Protracted Radiation Exposure

Dose (r)		Postexposure Effect
Acute (received in 24 hr or less)	200	None, but at threshold for work ineffectiveness*
	500	WI in about 12 hr; many die
	1000	WI in about 4 hr; most die
Protracted (received in from 24 hr to 2 weeks)	200	None, but at threshold for WI
	500	WI within 1 week; many die
	1000	WI within 4 days; most die

* Work Ineffectiveness (WI) indicates that the individual is no
longer able to conduct his normal duties satisfactorily.

Data obtained from Ref. A.5.

A.4 COUNTERMEASURES

To keep doses within the prescribed dose restrictions, it is often
necessary to employ countermeasures that will effectively reduce the
exposures to radiation. The emergency phase, which covers the period
during and immediately after fallout deposition, is the most critical
because in this phase the radiation intensities are highest. Two
methods of limiting dosage in this phase are practicable: evacuation
or taking shelter. Evacuation to uncontaminated locations in the face
of massive multiweapon attack with large thermonuclear weapons is
probably unrealistic because no "safe" areas may exist. The second
alternative, staying in an adequate shelter, has been deemed the better
countermeasure. A fallout shelter adequate for the more severe situa-
tions should attenuate the radiation field by a factor of 1000, and
have food and accommodations for 2 weeks' occupancy. Normal construc-
tion will not provide this degree of protection. Below-grade basement
shelters may be adequate, but if they provide inadequate protection
or are unavailable, a fallout shelter with at least 3 feet of earth
cover should be constructed (Ref. A.6). The thickness of some common
materials required to attenuate the gamma radiation from fallout is
listed in Table A.3.

During the recovery (decontamination and repairs) phase, unshielded
operations become feasible. In some cases, the radiation intensity may
have decreased sufficiently because of radioactive decay that the only
countermeasure required would be to restrict the time spent in the
fallout field (the stay time). In other cases, however, it would be
necessary not only to restrict the stay time but also to reduce the
intensity of the radiation by decontamination. Such radiation is most
readily accomplished by removing the fallout from contaminated surfaces
to a remote area. Firehosing and surface removal (scraping) are examples
of this technique (see Table 3). Another technique is to cover the
fallout with several inches of shielding material, usually earth, to
attenuate the radiation; however, this technique is cumbersome and,
aside from plowing (turning the fallout under), would rarely be employed.
Because radiation has properties of penetration and scattering, it
would always be necessary to decontaminate entire areas, not just a
few selected "hot spots." For example, to reduce the radiation to the
operator in a control room, it would be necessary to decontaminate the
roof of the control room, the roofs of any adjacent buildings or
structures, and the surrounding paved and unpaved areas out to a radius
of at least 200 feet from the control room. Firehosing might remove
90% of the fallout from the roofs and 95% from the paved areas;
scraping the unpaved area to a depth of 2 inches might remove 85% of
the fallout. The overall effectiveness of decontamination might be 90%

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Table A.3

Approximate Protection Factors for Gamma Rays From Fission Products
as a Function of Shield Thickness for Various Materials*

Protection	Material, Density, and Shield Thickness (Inches)					
	Lead (710 lb/cu ft)	Iron and Steel (490 lb/cu ft)	Concrete (144 lb/cu ft)	Earth (100 lb/cu ft)	Water (62.4 lb/cu ft)	Wood (Fir) (34 lb/cu ft)
2	0.3	1.2	4.5	6.0	10.0	17
10	1.0	2.7	9.7	13	19	36
100	1.9	4.8	16	23	33	62
1,000	2.7	6.8	22	32	45	88
10,000	3.5	8.8	27	39	56	110

* From Ref. A.1.

(often expressed as a decontamination residual number of 0.1), indicating that the man in the control room would receive only 1/10 of the dose he would have received if no decontamination were done. Since it is desirable to conserve as much allowable dosage as possible for use in recovery operations, the exposure received in transit and in living areas should be minimized. This can best be accomplished by using heavily-constructed vehicles operating over decontaminated access routes and by achieving a high degree of decontamination effectiveness in living areas which are occupied during nonwork hours.

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FOR
APPENDIX A

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         b.   Vol. II   Procedures and Guidelines
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         c.   Vol. III   Technical Information Relating
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APPENDIX B

PETROLEUM REFINERY CHARACTERISTICS

B.1 GENERAL

This appendix briefly describes the pertinent characteristics of the general types of refineries and a "typical" fuel-type refinery. This information is provided for the reader who is not familiar with petroleum refineries. The description is oriented toward those aspects of refineries connected with decontamination of radioactive fallout and emergency shutdown operations. If more information on refineries and their operations is desired, it is suggested that the reader consult Refs. 8 and 9 and trade journals, such as The Oil and Gas Journal.

B.2 REFINERY TYPES

Certain authors divide refineries into 6 general types according to the principal products processed, the size of the refinery (capability to process crude oil in barrels per day), and its complexity (defined in 4.2 of the text). Such a division is shown in Table B.1. In reality, each refinery possesses certain unique characteristics. Each is designed to process a particular type of crude oil and to produce certain specific products. In many instances, refineries have evolved to their present state over a period of many years; to various degrees, older equipment has been replaced by newer equipment as technological advances have been adopted.

Asphalt refineries are the simplest type, consisting usually of only a pipe still and possibly a vacuum still. The basic product, asphalt, is used almost exclusively in road construction and roofing. For many purposes, the product is shipped as a hot liquid; consequently, asphalt refineries are widely scattered to cover the consumer market. Asphalt refineries may also produce small quantities of gasoline and distillate stocks that are normally sold to larger refineries for further treatment. All units, storage tanks, and lines in asphalt refineries are steam jacketed to maintain the fluidity of the heavy materials. In case of a prolonged shutdown, the asphaltic components would solidify but could eventually be thawed out by the application

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Table B.1

Refinery Types and Complexity*

Type Refinery	Principal Products	Average Size (B/D)	Complexity Index
Asphalt	Asphalt	5,000	1.0
Fuel, independent	Gasoline & distillate stocks**	20,000	1.6
Fuel, major	Gasoline & distillate stocks	100,000	1.9
Asphalt & lubes	Naphthenic lubes & asphalt	3,000	2.3
Complete, major	Gasoline & distillate, waxes, lubes, asphalt	160,000	2.8
Pennsylvania lube	Motor & specialty motor oils	4,000	4.5

* Data obtained from Ref. 6.

** Gasoline stocks include motor fuel and aviation gas; distillate stocks include diesel fuel, kerosene, and heating oil.

of steam. The fire hazard in and around asphalt refineries is relatively low, but a serious source of danger is the unintentional introduction of water into hot asphalt, resulting in a "boil-over" and, often, a fire.

Fuel-type refineries are normally designed to optimize the production of motor fuel with concurrent production of diesel fuel, kerosene, fuel oil, and aviation gas. Smaller refineries (10,000 to 30,000 B/D), which are characteristic of the "independents," produce less high octane fuel and have less-complex operations. The larger refineries, which are usually associated with the major oil companies, use the more-complex units (for example, catalytic crackers rather than the less efficient thermal crackers) and produce more varied products. All fuel refineries are now installing processes such as catalytic reforming and hydrotreating to improve the quality of fuels produced but not the quantity. Fuel-type refineries are widely scattered but tend to center around producing fields or near ports where water transportation of the crude is feasible.

The lube refineries are unique, being small, independent processing plants that use special types of crude to produce high-grade lubricants. The Pennsylvania refineries are well known for their motor oils and related lubes. "Asphalt and lube" refineries utilize heavy crudes, found in a half dozen other states, to form the naphthenic lubes used in the auto industry and elsewhere. These refineries also produce asphalt as a by-product. The independent lube refineries produce about 15% of the lubricating oils made by the entire industry.

Complete refineries produce, in addition to fuels, lubes, asphalt, greases, waxes, and usually a variety of petrochemicals. The petrochemicals, manufactured from certain cuts of the crude, usually by a subsidiary of the refinery, range from the raw materials for plastics, paints, and detergents to adhesives and insecticides. However, the primary operation of the complete refinery is the production of gasoline and distillate stocks. Complete refineries, which are mainly operated by the major oil companies, range in size from 50,000 to 360,000 B/D capacity.

B.3 DESCRIPTION OF REFINERIES AND THEIR OPERATION

Types of operations and marketed products will vary from refinery to refinery but a moderate-sized (50,000 B/D) fuel-type refinery might be considered "typical" in many respects. Such a refinery might produce regular and premium grade gasoline, diesel fuel, jet fuel, kerosene, heating oil, and aviation gasoline. A refinery of this size

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is equipped with two or three crude, or pipe, stills in which the preliminary separation of the crude would be made. The heavier fractions from the crude stills are put through a vacuum still to separate the fuel components from the asphalt residuum. Selected lighter fractions are sent through a cracking unit, either a modern catalytic cracker or the obsolescent thermal cracker, creating larger yields of the gasoline fraction. The motor fuels would finally be processed in the catalytic reformer and hydrotreating units to increase the quality of the product. High octane gasoline would be produced, from various light fractions, in the alkylation and polymerization units. These high octane fractions would then either be sold as avgas or blended, along with tetra ethyl lead, into motor gasoline.

The location of a refinery is decided primarily by transportation facilities, labor supply, water sources, and topography. Many refineries are located on a navigable river or inlet near a large city on relatively level ground. A refinery may be divided into the following working areas: office, processing, power, shops, packaging and loading, bulk product storage, and crude storage. The process area is generally compact and complex; other areas tend to sprawl. Most refineries will have storage capacity for crude oil for up to 20 days running time; an almost equivalent amount of storage for products is normally available.

A given refinery is designed to operate on one crude or a specific mixture of crudes. The most desirable crude would be a sweet (non-acidic) light crude with an inherently high gasoline content. The most undesirable crude--but sometimes economically feasible--would be a heavy, sour (acidic) crude. A refinery could switch to using a different type of crude only after considerable conversion of equipment.

Refineries are large consumers of utilities, particularly electricity, water, and steam. In 1956, the average refinery consumed 3.9 kwh per barrel of crude charged (200,000 kwh per day for a 50,000 B/D refinery), of which 37% was self-generated and 63% purchased from outside sources.[8] In larger refineries in particular, the availability of outside electrical power is essential to operation.

The average refinery uses 140 lb of steam per barrel of crude charged (7,000,000 lb/day for a 50,000 B/D refinery). In smaller refineries, the steam is internally generated; many small refineries can operate on steam alone, being in a real sense self-contained units. In newer, large refineries, steam and electricity may be supplied by an adjacent utility company in return for boiler fuel. Some refineries are dependent on natural gas for their internal fuel requirements.

Water consumption varies both with type of operation and ambient water temperature; the typical refinery would use 650 gal/day per barrel of crude charged (32,500,000 gal/day for a 50,000 B/D refinery). Only a small percentage of the water used needs to be high-quality fresh water; the remainder, used primarily for cooling purposes, can be brackish or saline. Water consumption and costs can be lowered by the recirculation of water through cooling towers, or the installation of air-cooled condensers.

Larger refineries have elaborate waste water systems to handle and purify the vast amounts of discharge water. These same systems normally are, or could be, used for the disposal of surface water run-off. In a "typical" refinery, oil-contaminated water is sent to an oil-water separator, where sediment sinks to the bottom and oily wastes are skimmed off the top, clean water being returned to the water source. In a situation where fallout occurs and firehosing is employed for decontamination, the sewerage system would play a vital role. The fallout would be flushed into the sewers and, assuming the sewers are not clogged by the quantity of material, would eventually reach a separator where the fallout would settle in 3 to 6 feet of water. Disposal of the accumulated fallout could probably be postponed for months or years without affecting the efficiency of the separator greatly.

Fire is the most dangerous hazard in any type of refinery, occasionally resulting in devastation to large portions of the plant. For the period 1934-1953 the average number of fires per 100 refineries per year was 164, with an attendant fire loss of $1,900,000 (Ref. 8). Most fires occur in the process area and, with the prompt attention of the firefighting force,* are controlled. However, some fires occur spontaneously (primarily from lightning), particularly in storage areas. In all probability if such a fire were to start in an unmanned refinery, the entire refinery would be lost.

Because of the acute fire hazard, an adequate supply of high pressure water is available throughout the entire plant area for firefighting purposes. This water supply along with the available firehoses, could equally well be used for decontamination. Some refineries do use the fire system for housekeeping purposes, and for washing down process units and paved areas regularly. Refineries may also rent street sweepers or flushers to clean up paved areas. Many refineries have front-end loaders which are used for routine clean-up operations.

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* All plant personnel are regularly trained in firefighting and in time of emergency augment the regular fire department.

Even the best managed and most modern refineries are ill-prepared for emergency shutdown situations. Although a refinery is equipped with the latest recorders, regulators, and remotely controlled valves, trained manpower in adequate number remain essential for startup and shutdown, as well as for normal operation. Automation, in the sense that an operation can be programmed, has not yet been realized in the industry. Nor is it possible for one man to sit in a central control room, watching dials and pushing buttons, to bring a big unit down. Rather, men must scatter to various points to perform manipulative tasks.

B.4   REFINERIES IN THE UNITED STATES

Some general remarks are made here concerning the petroleum refining industry of the United States. In particular, the relative production and capacities of refineries are shown by size. The data may be of interest in the preparation of an optimum schedule of recovery.

As of January 1, 1960, the total number of refineries in the U. S. was 292 (Ref. 4). These refineries were located in 38 states, with Texas and California in the lead with 57 and 37 refineries, respectively. The average refinery size had a capacity of 34,000 B/D. The total productive capacity of the U. S. refinery industry was 9,700,000 B/D. Approximately 26% of this amount was produced in Texas and 14% in California.

From Fig. B.1, it can be seen that only 10% of the total number of refineries, representing refineries greater than 70,000 B/D, produce 50% of the total U. S. output. Conversely, 50% of the total number of refineries (that is, those of less than 8,000 B/D capacity) produce less than 10% of the total output. Thus, small refineries, although numerous and widely dispersed, are a relatively unimportant factor in the total refinery industry. Furthermore, most of the small refineries produce only asphalt or other specialty products. Medium and large refineries, on the other hand, supply the basic fuels as well as a wider range of specialty products.

In a recent study,[10] Stanford Research Institute (SRI) estimated that the 1960 consumption of various petroleum fuels was as follows:

Gasoline:	B/D
Motor gasoline	4,096,000
Aviation gasoline	164,000
	4,260,000

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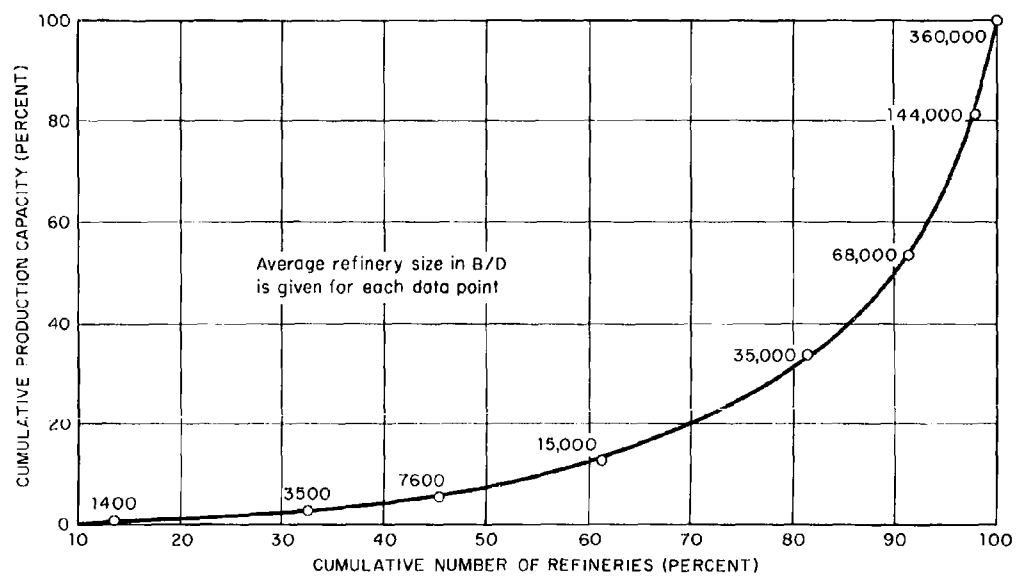
Fig. B.1   Production Capacity <u>vs</u> Number of U. S. Refineries, 1 January 1960

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Distillate:

Heating and Cooking	1,189,000
Industrial fuel	143,000
Railroads	233,000
Ships	52,000
Jet fuel	375,000
Miscellaneous	261,000
	2,253,000

These values are for a period when refineries were running at about 80% capacity. SRI also estimated that stocks on hand for this period were 242,400,000 barrels of gasoline and 278,360,000 barrels of distillate. These stocks were located in bulk plants and terminals, refineries, and pipelines.

APPENDIX C

THE QUESTIONNAIRE

     This appendix contains a sample of the questionnaire and the forwarding letter which was sent to each of the nine California refineries contacted.

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco 24, California

In Reply Refer
To File:
911
LJM:sm

X Oil Company

California

Attention: Plant Manager

Dear Sir:

This Laboratory has been assigned a research task by the Office of Civil
and Defense Mobilization to determine the magnitude of the effort and
the time required to recover various types of industrial and service
facilities in the event they were contaminated by radioactive fallout
resulting from a nuclear attack. Such information is required by the
National Damage Assessment Center in generating feasible production
programs within the limits of surviving resources for use in planning
post-attack recuperation of the economy of the United States. Recovery
of oil refineries has high priority in the study.

This will be an operations research type of study. The basic approach
will be to become familiar with the physical and operational aspects
of a refinery, to develop a recovery model or plan based on the informa-
tion obtained there, to develop a computational scheme based on the
recovery model, and to compute the required results for many individual
refineries or classes of refineries using input information obtained
by correspondence and direct contact. Your refinery has been chosen
as being one which would reflect certain characteristics of refineries
pertinent to this study.

The purpose of this letter is to acquaint you with this study, to mail
you a questionnaire, and to initiate arrangements for us to subsequently
discuss and pick up the completed questionnaire. As you will note in
the questionnaire we are specifically interested in the following:

(a) General description of the plant,
(b) Size and description of the work force,
(c) Description of the water supply, firefighting capabilities, and drainage system,
(d) Damage effects of rapid emergency shutdowns on plant operations.

We have assigned two research investigators to prosecute this study. Mr. L. Minvielle is the project leader; he will be assisted by Mr. Wm. Van Horn. If possible Mr. Minvielle and Mr. Van Horn would like to visit your plant during the week of 24 October to 28 October 1960. If you approve of their visit at this time, please write to them at the address given below informing them who to contact at your plant.

Larry Minvielle, Code 911
U.S. Naval Radiological Defense Laboratory
San Francisco 24, California

It should be pointed out that this study has no connections with local civil defense matters and that we do not intend to offer advice or make recommendations unless specifically requested to do so by yourself. In addition, whatever information is obtained from you will be treated with the utmost secrecy.

Sincerely yours,

E. B. ROTH
Captain, U.S. Navy
Commanding Officer and Director

Encl:
(1) Questionnaire

QUESTIONNAIRE

Dear Sir:

In order to serve as a guide in answering this questionnaire and to
satisfy a certain amount of curiosity which has been generated in the
reader's mind, a brief description of the situation considered and of
the objectives of the present study follows. A nuclear detonation occurs
at some distance from the plant. Because of this distance, no physical
damage is inflicted on the plant by the blast and fire effects of the
burst. However, the plant is located within the regions of fallout;
the radioactive fallout begins to descend upon the plant sometime after
the burst. Radioactive fallout would be deposited over the surface of
the earth as a fine powder having a thickness of from 0.1 to 0.5 inches.
Admittance to this contaminated area would be hazardous or impossible
for some time because of the harmful rays emanating from this debris.
To protect themselves from the radiological rays, plant personnel
would have to spend some time of the order of days in shelters; some
of the existing plant buildings could be modified in many cases to
furnish this protection. Later the plant personnel could emerge and
prepare to occupy the plant. To shorten the time of denial to the plant,
the radioactive debris would have to be removed first from the more
vital areas of the refinery. This removal, called decontamination,
can usually be accomplished in a manner similar to that practiced in
the removal of ordinary dirt, i.e., by firehosing, sweeping, etc. A
portion of the questionnaire is devoted to obtaining information
necessary to planning this operation.

In addition, the questionnaire is oriented towards determining the time
required for emergency close-down of plant operations and towards
anticipating the consequences on plant equipment and future resumption
of operations of insufficient warning time. Before the arrival of
fallout at the plant and before personnel could leave the equipment
for a prolonged period of the order of from 2 to 6 weeks, it would be
necessary to close down the plant if one were to expect to resume
operations at some later date without performing major repairs. From
conversations with a limited number of refinery personnel, it appears
that under normal conditions, it requires something of the order of 48
hours to safely close down a refinery. It was estimated that under
emergency conditions, if the plant personnel had been trained and some
preparations had been made, a refinery could be closed down in a minimum

time of 3 hours without serious damage to plant components. Some of the products would have to be dumped and certain procedures, normally not acceptable, would have to be adopted. However, the plant could resume operations several weeks later without having to undergo major repairs. Through this questionnaire it is hoped to obtain a consensus of opinion on estimates of minimum shutdown times under emergency conditions as well as estimates of time and manpower.

It is realized that for certain questions posed, it is impossible to give reliable data; it is suggested that for such cases, a best guess be made. For the sake of economy involved in answering the questionnaire, it may be noted that a high degree of accuracy is not required. If the reader desires to comment on any phase of this study which may be of value to the reliability of the analysis, his remarks will be welcomed.

We thank you for your cooperation.

QUESTIONNAIRE

1. MAP

A map of the refinery is desired to determine the size and other
features of the vital area. On this map please identify all major
components necessary to the manufacture of the refinery products. In
addition, identify such auxiliary equipment as power stations, steam
generating plants, etc. The scale to which the map is drawn should be
included. A schematic drawing of the water distribution system would
be desirable as well.

2. TERRAIN FEATURES

(a) Is the refinery near a large body of water such as a lake,
river, ocean, etc? If yes, plese identify this body of water.

(b) Is the terrain of the refinery generally flat or hilly?

3. WORK FORCE

(a) What is the total number of people employed by the refinery?

(b) Please list the total number of people in each of the
following seven main groups:

(1) ADMINISTRATIVE:

Executive--Vice president, manager, superintendent, purchas-
ing agent, chief engineer, etc.

Bookkeeping--Accountant, assistant accountants, timekeeper,
cashier, etc.

Clerical--Assistant purchasing, office manager, clerk,
telephone operators, secretaries, stenographers, etc.

(2) TECHNICAL:

Engineering and design--Process, maintenance, assistant
chief engineer, corrosion, inspector, assistant inspector, electrical
structural, draftsmen, librarian, development, etc.

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Laboratory--Chief chemist, chemists, analysts, testers, engine operators, sample boy, bottle washers, gas testers, etc.

(3) PRODUCTION and MANUFACTURE:

Management--Chief operator, assistant superintendent, night superintendent, labor-relations manager, etc.

Operations--Shift foreman, shift analysts, cracking stillman, topping stillmen, stillmen helpers, firemen, etc.

(4) PUMP HOUSE and UTILITIES:

Marine manager, crude transfer, product transfer, water circulation, loading rack gagers, TEL blending, utility foremen, power-plant supervisor, firemen, etc.

(5) MAINTENANCE and REPAIR:

Maintenance foreman, chief machinist, master mechanic, electrician foreman, straw bosses, machinists and helpers, mechanics and helpers, master welder and welders, blacksmiths, tinners, boilermakers, pipefitter foreman and helpers, instrument mechanics and helpers, electrician helpers, carpenters, insulators, painters, masons, pump repairmen, truck drivers, riggers, burners, crane operators, yard labor, grader operators, etc.

(6) PROTECTION:

Janitors, watchmen, guards, guides, timekeepers, etc.

(7) WAREHOUSE, etc.:

Manager, stock clerks, receiving clerks, unloaders, packers, salvage-yard workers, etc.

(c) List any additional outside source of manpower.

4.   WATER SUPPLY AND SEWERAGE

(a) What would be the maximum water flow in gals/hr and operating pressure that the plant could pump into the fire-fighting system if the manufacturing process was closed down?

(b) What is the source of water supply for the plant? How many and what size main lines supply this water?

(c) What are the main pumping facilities and what are their capacities? Indicate these on the map.

(d) How does your plant handle storm drainage? If storm drainage is fed into the main sewer line, what is the range of the pipe sizes and the approximate slope of the feeder lines? What is the approximate size and slope of the main sewer lines? Where and of what capacity are the pumps in the sewerage system? How are these pumps powered?

(e) What type-length and sizes-of firehoses are there at the plant?

5. UTILITIES

(a) What are the sources of electrical power for the plant-- outside and local? What would be the condition of the plant if it had to depend solely on local power?

(b) How are the raw and refined products transported in and out of the plant--by pipeline, by ship, by railroad, etc?

6. EMERGENCY SHUTDOWN TIMES

The objective of this paragraph is to obtain a set of curves for your refinery which would show the times, manpower, and mandays required to resume various degrees of production for various values of shutdown time. The type of information desired is illustrated in Fig. 1. It is requested that the "accuracy" of these estimated curves be reflected by showing each curve as a band.

To make these estimates it is suggested that the following assumptions be made:

(1) Personnel of the plant have been trained and drilled in emergency shutdown.

(2) Some preparation has been made by the plant to expedite the shutdown procedure.

(3) The normal complement of people usually employed during the day work shift is present during the shutdown operation.

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(4) For the purposes of this analysis, no hazard is threatening the personnel involved in the shutdown operations.

(5) Electricity and gas are available from outside sources for the startup operation if the refinery operates from outside power.

(6) Materials required for repairs and operation are available with no delay.

Make any other assumptions needed to furnish the answers desired and state what they are.

It is requested that curves of the type shown in Fig. C.1 be prepared for the following percentages of resumption of production - 10%, 30%, and 100%. Give the manpower involved in the repairs for each case. The total number of men performing the repairs should be of the same order of magnitude as the normal complement of the refinery.

7. MISCELLANEOUS

(a) Besides firehosing and sweeping, are there other methods used to clean the plant grounds? These would include the use of motor sweeping, and flushing equipment. If yes, please list them.

(b) Is the drainage system adequate to handle the maximum water flow? If not, what is the maximum flow rate it can handle?

(c) What are the three main products manufactured and in what quantities - barrels per day?

(d) Does your plant make extensive use of automation?

(e) Does your plant have its own steam and power plant? If yes, does it furnish all the power for the refinery?

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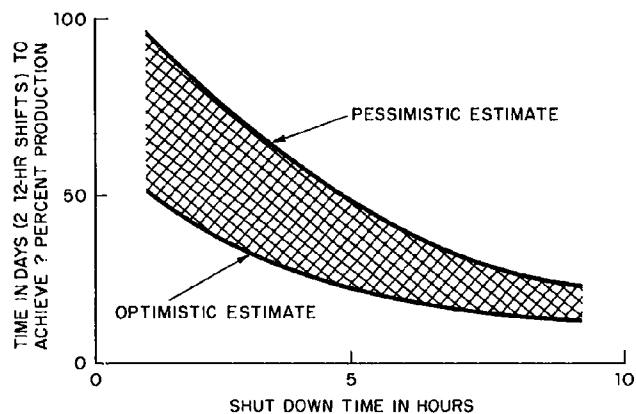
APPROXIMATE MANPOWER REQUIREMENTS TO RESUME PRODUCTION

Shut down time in hours	Men per shift
1/2	?
3	?
6	?

1. Assume a round-the-clock work schedule and let each man work a 12-hr work shift.

2. Curves such as these are required for 10%, 30% and 100% resumption of production.

Fig. C.1   Days Required to Achieve ?% Refinery Production
After Emergency Shutdown of Various Lengths

APPENDIX D

COMPARISON OF RECOVERY SCHEDULES BASED ON THREE
DIFFERENT DECAY RATES

The sponsor requested that the effect of assuming various possible radioactive-decay rates of the fission products on the recovery schedules of Section 5 be investigated. This is done in this appendix. Comparisons are made on the basis of (1) earliest entry times and (2) accumulated doses of the recovery personnel. Three decay rates in common usage are considered: the one that follows the $t^{-1.2}$ law, identified as $I(1.2)$; the one discussed in Ref. 2, referred to here as the $I(F)$ curve; and the one used in Ref. 1 and in this study, $I(R)$. These three decay rates are shown in Fig. D.1. Two situations are considered. In both cases, it is assumed that the recovery personnel have received no radiation dose before the permissible earliest entry time, and that they accumulate dose during work hours only; they retreat to a radiation-free area during nonwork hours.

D.1   AN IDEALIZED SITUATION

The first situation is an idealized one: the fallout is deposited uniformly over the plant and remains undisturbed by the weather and no decontamination is performed. The plant personnel wait before entering the radiation field to start recovery so that they will not receive doses in excess of 30 roentgens for any one day, 230 roentgens for any 2 weeks after entry, or 1000 roentgens for the first year after entry. A work schedule of 8-hour/day and 6 days/week is assumed. The earliest entry times for this situation are given in Table D.1. The largest earliest entry time values for any standard intensity have been underlined. For standard intensities of 3000 r/hr or less, the earliest entry time is governed by the one day dose. The entry times for the three decay rates do not differ greatly. For standard intensities of 10,000 r/hr or greater, the entry time is governed by the 1000 r/yr accumulated dose. The two extreme values of earliest entry time for this intensity are 68 and 39 days, respectively, for $I(1.2)$ and $I(R)$. Similarly, for the 30,000 r/hr the earliest entry times are of the order of 350 and 134 days. The values are included as a matter of interest. One cannot reach any conclusions as to the effects of the three decay rates on the times for recovery or the doses
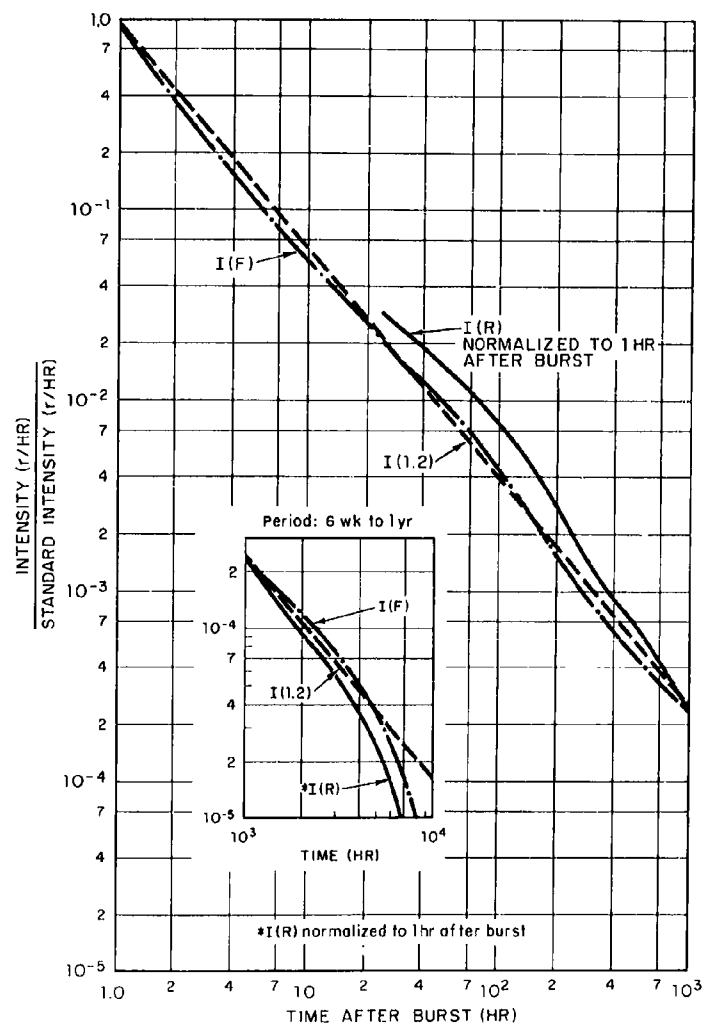
Fig. D.1 A Comparison of Three Decay Rates for Fission
Product Activity

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accumulated because of the unrealistic case considered. The next situation forms a preferable basis for comparison.

D.2 A SECOND SITUATION

In working an acceptable recovery schedule in this study, it was considered important to avoid long delays of the order of 100 days or more that were encountered in the previous situation. Furthermore, although the dose restrictions imposed on the problem were lenient (high doses allowed), the recovery was planned in such a manner as to keep the accumulated doses down, but not necessarily to a bare minimum. It was found that this could be done by decontaminating the vital area with nominal effort and time--particularly nominal when one considers the large repair effort needed because of fast-emergency-shutdown damage. Although an optimum solution was not attempted, it is believed that an acceptable one from the viewpoint of common sense has been achieved. The state of knowledge is not sufficiently advanced in radiological defense at the present time to consider a more sophisticated approach. Table D.2 summarizes the results of the computations for this situation. Column A shows the earliest entry times into the undecontaminated field as controlled by the 30-r/day dose restriction. Column B shows the doses accumulated during the first two weeks in the undecontaminated field; column C, during the first year. Estimates of the residual numbers required to keep the accumulated doses within the dose restrictions imposed have been calculated. These values are underlined in Table D.2. For a given standard intensity, the effort required to decontaminate to the level indicated by the underlined values is about the same for all three decay rates. For example, for an intensity of 10,000 r/hr, it would be necessary to decontaminate to the lowest underlined values for each decay rate, i.e., to 0.64 for $I(1.2)$, to 0.65, $I(F)$, and to 0.73 $I(R)$. Practically, the differences in effort and time required to achieve these three effectiveness numbers would hardly be discernible. The case for the 30,000 r/hr standard intensity can be analyzed similarly.

D.3 CONCLUSIONS

For the recovery schedules presented in Section 5, the times for recovery and the doses accumulated by recovery personnel would not have differed significantly whichever of the three decay rates had been adopted. This is true if one accepts the differences in earlier entry times of column A, Table D.2, as not being significantly different. Furthermore, when one compares these relatively small differences with the much larger uncertainties in the estimated repair times, one must conclude that the errors in entry times are negligibly small in their contribution to the overall degree of accuracy of the study.

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Table D.1

Earliest Entry Time vs Dose Restriction for Three Decay Rates-- No Decontamination

Standard Intensity (r/hr)	Imposed Dose Restriction								
	30 r per day			230 r per 2 wk*			1000 r per yr*		
	I(1.2)	I(F)	I(R)	I(1.2)	I(F)	I(R)	I(1.2)	I(F)	I(R)
100	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
300	1.2**	1.2	2.4	< 1	< 1	< 1	< 1	< 1	< 1
1000	3.9	4.2	6.4	1.9	2.0	3	< 1	< 1	< 1
3000	11.0	9.2	12.9	7.8	7.8	12	4.2	3.2	6
10000	30	25	31	37	32	34	68	60	39
30000	72	77	67	100	115	90	350	172	134

* For exposures starting at entry time.

** Underlined values indicate governing dose restriction for given standard intensity.

Table D.2

Recovery Dose vs Earliest Entry Time for Three Decay Rates-- Nominal Decontamination

Standard Intensity (r/hr)	A Earliest Entry Time* (days)			B Dose for 2 wk** (r)			C Dose for 1 year** (r)		
	I(1.2)	I(F)	I(R)	I(1.2)	I(F)	I(R)	I(1.2)	I(F)	I(R)
100	< 1	< 1	< 1	-	-	-	-	-	-
300	1.2	1.2	2.4	100	94	118	162	160	164
1000	3.9	4.2	6.4	166	132	195	358	312	320
3000	11.0	9.2	12.9	237 ***0.9	197	243 0.9	737	713	600
10000	30	25	31	304 0.75	275 0.82	314 0.73	1560 0.64	1530 0.65	1200 0.85
30000	72	77	67	335 0.68	343 0.67	352 0.65	2900 0.35	2600 0.38	2060 0.48

* Controlled by 30-r/day dose restriction.

** For exposures starting at entry time.

*** Underlined values denote residual numbers required to keep accumulated doses within specified dose restriction.

APPENDIX E

EFFECT OF IGNORING THE 30-r/DAY DOSE
RESTRICTION ON EARLIEST ENTRY TIME

The sponsor requested that the effect of ignoring the 30-r/day dose
restriction on the earliest entry times of Section 2 be investigated.
This is done in this appendix. Earliest entry times and doses accumulated
by recovery personnel have been computed for the case in which the 30-
r/day dose restriction is ignored. Hence, the dose restrictions used
here are 230-r/2 wk and 1000 r/yr. The values of the remaining para-
meters affecting earliest entry times and dose histories are the same
as those used for the case in which all three of the dose restrictions
are used so that comparisons between the two cases could be made
(see Section 2).

E.1 EARLIEST ENTRY TIMES

Earliest entry times depend on the permissible dose to the recovery
crews, the standard intensity, the work schedules, and the residual
numbers prevailing during recovery. Calculations show that the doses
that would be accumulated during the nonwork hours when personnel are
in a staging area would be small. In addition, they show that, if the
230-r/2 wk dose restriction is not exceeded when decontamination is
performed, the 1000-r/yr restriction will be met.

As a first step in determining the earliest entry time, the dose
accumulated during the first two weeks of recovery, D_{2wk}, is computed
by the following equation:

$$D_{2wk} = D_D + D_R \qquad\qquad (E.1)$$

where

D_D = dose accumulated during the decontamination phase, which
may require four days.

D_R = dose accumulated by the recovery personnel from the time
decontamination is completed to 2 wk after entry for repairs.

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The dose accumulated during decontamination is given by:

$$D_D = F_T \, F_D \, (D_1 + D_2 + D_3 + \ldots + D_n) \qquad \text{(E.2)}$$

and, the dose during the remainder of the 2-wk period by

$$D_R = F_T{}' \, F_D{}' \, (D_{n+1} + D_{n+2} + \ldots + D_{14}) \qquad \text{(E.3)}$$

where

F_T = residual number arising from fraction of day worked during decontamination. Two cases are considered: F_T = 8/24 and 4/24.

F_D = residual number during the decontamination resulting from the decrease in intensity as the decontamination progresses.

$F_T{}'$ = residual number arising from fraction of day worked after decontamination is completed and repairs are started ($F_T{}'$ = 8/24).

$F_D{}'$ = residual number achieved by decontamination ($F_D{}'$ = 0.1).

D_1, D_2, D_3, ... D_n = free-field doses that would be received during the first day, second day, third day, ... and the nth days when decontamination would be completed, for 24 hr per day occupancy in the original undisturbed radiation field.

D_{n+1}, D_{n+2}, ... D_{10} = free-field doses that would be received during the $(n+1)^{th}$ day, $(n+2)^{th}$ day, ... and 14th day, for 24 hr per day occupancy in the original undisturbed radiation field.

Thus,

$$D_{2wk} = F_T \, F_D \, (D_1 + D_2 + D_3 + \ldots + D_n)$$
$$+ F_T{}' \, F_D{}' \, (D_{n+1} + D_{n+2} + \ldots D_{14}) \qquad \text{(E.4)}$$

To facilitate the computations of accumulated doses, the values of Table 3.9 of Ref. 1 were used. Table E.1 gives the pertinent values of D_1, D_2, etc., that were substituted in Eq. E.4. Figure E.1 shows the doses accumulated during the 2-wk period for various entry times, T_E, and decontamination times, T_D. The values of the other parameters are shown on the figures. The earliest entry times consistent with the allowable maximum dose of 230-r/2 wk can then be read directly from the figure at the point indicated on the vertical axis. These times are

120
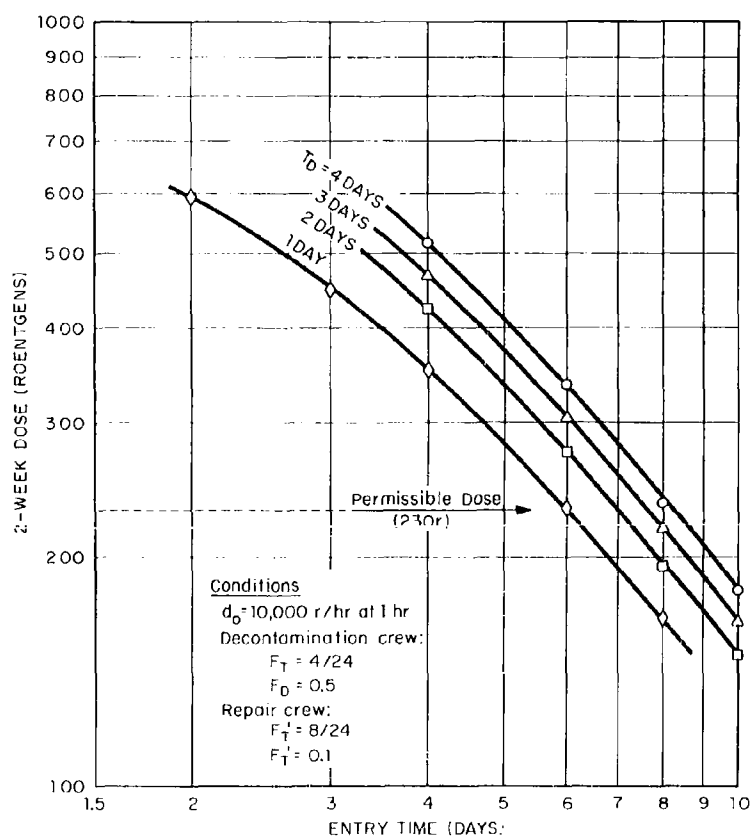
Fig. E.1 Earliest Entry Time vs 2-Wk Dose for Various
Decontamination Times

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Table E.1

Free-Field Accumulated Doses (r) for 1000-r/hr Standard
Intensity and Continuous Occupancy*

Entry Time T_E	Intensity at Entry Time	Duration of Mission		
		24 Hours	2 Weeks	1 Year
		(A)	(B)	(C)
1 day	29.2	524	1765	2414
2 days	16.2	328	1279	1908
3	11.1	230	993	1597
4	8.06	172	797	1384
5	6.15	132	650	1219
6	4.81	104	554	1105
7	3.76	83.0	462	999
8	3.07	67.1	403	927
9	2.50	55.1	354	862
10	2.06	46.0	317	808
11	1.76	43.1	286	768
12	1.51	33.6	251	721
13	1.30	29.3	241	700
14	1.13	26.2	230	675
3 wk	0.900	16.3	156	539
4	0.470	10.8	112	447
5	0.331	7.75	87	384
6	0.256	6.11	67	336
2 mo	0.150	3.54	49	259
3	0.0853	2.01	26	179
4	0.056	1.34	16	130
6	0.032	0.77	7	73

* Data from Table 3.9 of Ref. 1; to compute accumulated doses for
a dose rate, d_o, other than 1000 r/hr, multiply the dose values,
in columns A, B, and C by the factor: $\dfrac{d_o}{1000}$

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6.0, 7.0, 7.8, and 8.2 days for a total decontamination time of 1, 2, 3, and 4 days, respectively.

By a similar method to the one just described, the earliest entry times were computed for other controlling parameters values and are given in Table E.2.

Table E.2

Earliest Entry Time for 230-r/2-wk
and 1000-r/yr Dose Restrictions

Standard Intensity (r/hr)	F_T	F_D	$F_T{}'$	$F_D{}'$	Days Required to Decontaminate			
					1	2	3	4
1000	8/24	1.0	8/24	0.1	< 1	1.7	*	*
3000	"	"	"	"	4.1	5.9	*	*
10,000	"	"	"	"	10.4	14.4	*	*
30,000	"	"	"	"	26.5	35	*	*
1000	4/24	0.5	8/24	0.1	< 1	< 1	< 1	< 1
3000	"	"	"	"	1.4	1.8	2.2	2.4
10,000	"	"	"	"	6.0	7.0	7.6	8.2
30,000	"	"	"	"	16.5	18.7	20.6	22.4

* With the decontamination crew working 8 hr/shift, decontamination would be completed in two days; hence, no values are shown.

E.2 ACCUMULATED DOSES FOR RECOVERY PERSONNEL

The accumulated doses for recovery personnel are given in Table
E.3. For standard intensities of 100 and 300 r/hr, no decontamination
was performed; for the higher standard intensities, the vital areas
were decontaminated. The tabulated dose values for 100, 300, and 1000
r/hr have been approximated; although entry time is less than one day,
the accumulated doses are based on an entry time of one day after burst.

The values of the pertinent parameters for this table are as
follows:

Decontamination crew: $F_T = 4/24, F_D = 0.5$

Repair crew: $F_T' = 8/24, F_D' = 0.1$

Table E.3

Accumulated Dose for Dose Restrictions of
230-r/2wk and 1000-r/yr

Standard Intensity (r/hr)	T_E (days)	$T_E + T_D$ (days)	1st Day Dose (r)	2-wk Dose (r)	1-yr Dose (r)
100	< 1	< 1	17	60	80
300	< 1	< 1	52	180	240
1000	< 1	< 2	86	230	260
3000	1.8	3.8	89	230	288
10,000	7.6	10.6	61	230	407
30,000	22.4	26.4	38	230	605

APPENDIX F

COMPARISON OF REPAIR MAN-DAYS AND TIMES FOR LARGE AND SMALL REFINERIES

F.1 GENERAL DISCUSSION OF ANALYSIS

This appendix presents a comparison of the man-days and days required by large and small refineries to repair damage from emergency plant shutdown (one man-day is taken as 24 man-hours). The data obtained through Item 6 of the Questionnaire (Appendix C) form the basis for the comparison.

The shutdown times used in the body of the report are considered here. The case of the 1-hr shutdown time is considered first and in some detail to show the analytical procedure used. Only the final results are presented for the 3-hr and 6-hr shutdown times.

Figure F.1 shows repair effort in man-days vs refinery size for 100%, 30%, and 10% recovery of normal production capacity. Refinery size is expressed in barrels of crude oil processed per day. The man-days are arithmetic averages of the optimistic and pessimistic estimates requested in Item 6 of the Questionnaire. Only refineries larger in size than 10,000 B/D have been considered, since the data for the smaller refineries were not given in sufficient detail for this phase of the analysis. Figure F.2 was obtained directly from Fig. F.1 by cross-plotting.

Figure F.3 shows the repair effort in man-days required to repair various combinations of equal-size refineries. Each combination would process a total of 200,000 B/D of crude oil. The man-days required to repair a 200,000 B/D refinery were obtained from Fig. F.2 for the three percent production capacities. For one 100,000 B/D refinery, the man-days were read from Fig. F.2 and multiplied by 2 to obtain the total man-day requirement. The total man-days required for the other combinations were obtained similarly.

Figure F.4 shows total number of employees vs refinery size. These data are based on 10 California refineries and 4 out-of-state refineries. For this analysis, the repair work force was taken as
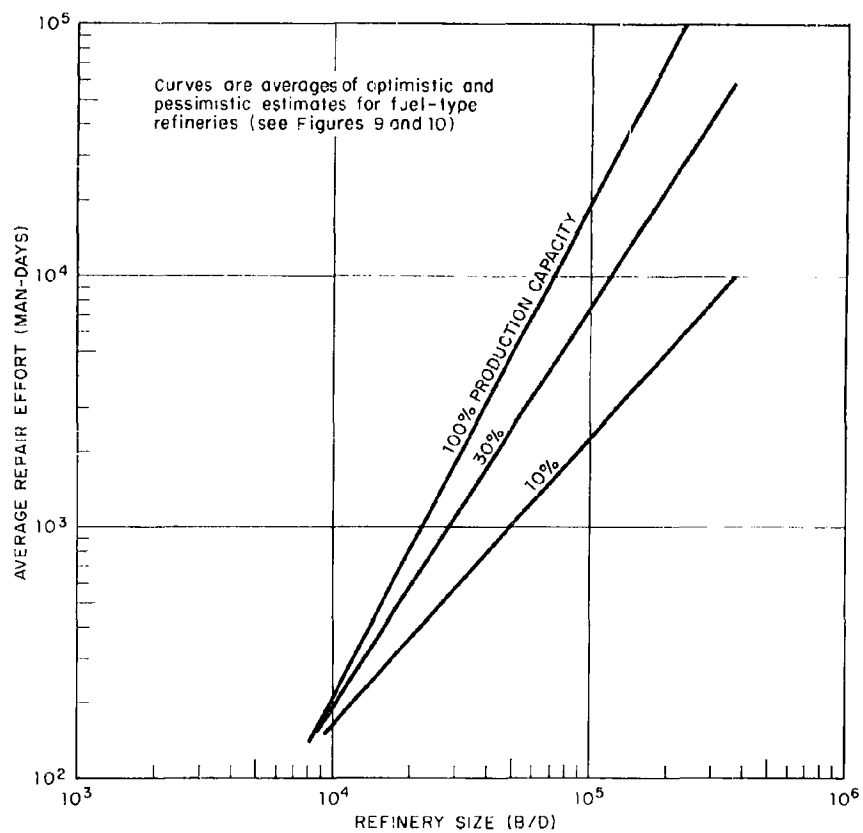
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Fig. F.1 Average Repair Effort vs Refinery Size for 1-Hr
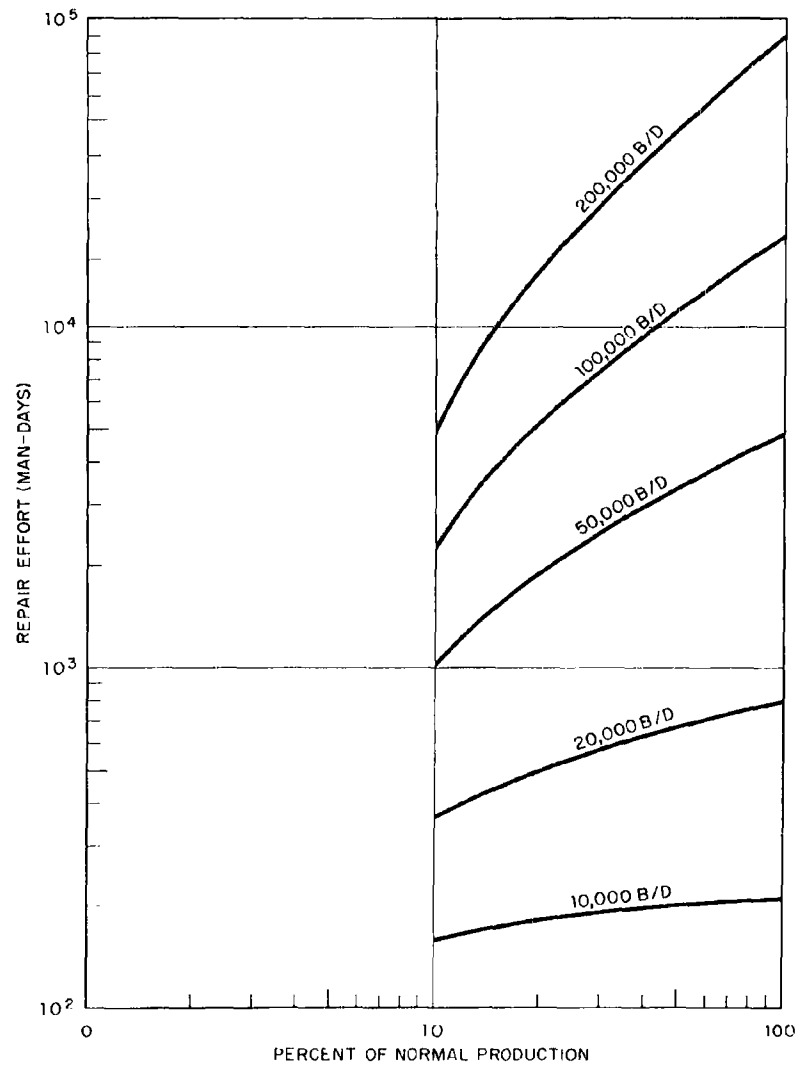Shutdown Time and Three Production Capacities

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Fig. F.2 Repair Effort vs Percent Production Capacity for
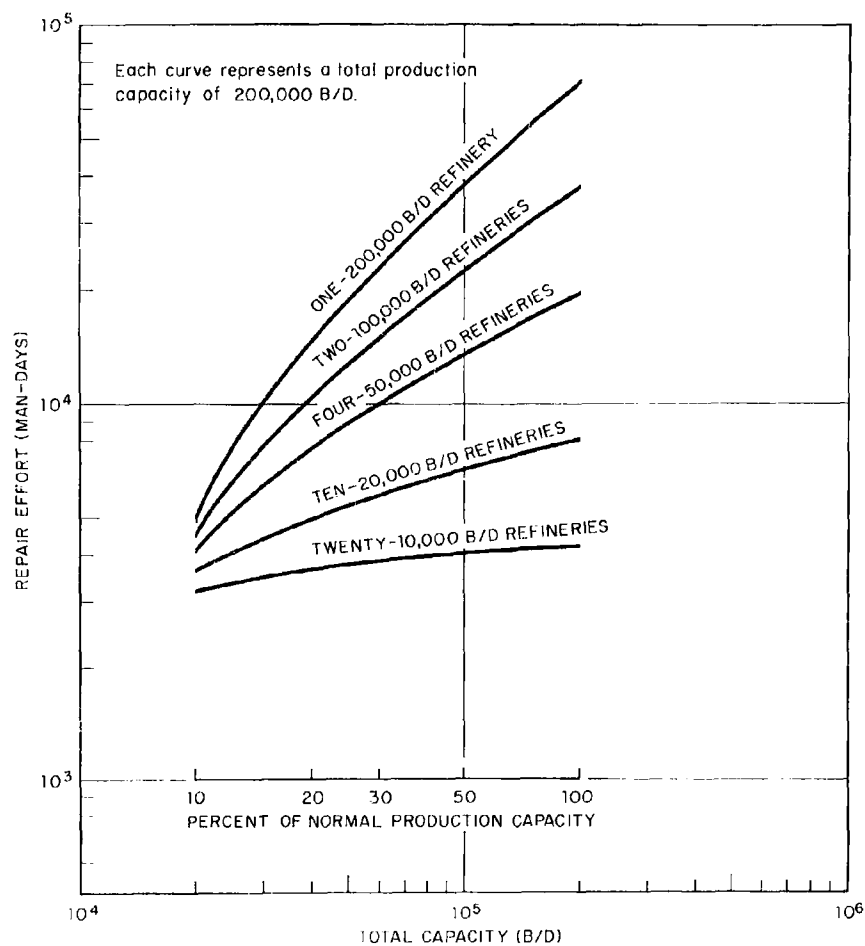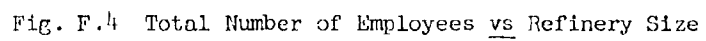Various Sized Refineries and 1-Hr Shutdown Time

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Fig. F.3 Repair Effort vs Total Capacity for Various
Refinery Combinations and 1-Hr Shutdown Time

Fig. F.4 Total Number of Employees vs Refinery Size

75% of the total number of employees.

Figure F.5 shows, for the 1-hour shutdown time, the days required to repair the above-mentioned combinations of refineries, exclusive of decontamination, so that the total production capacity of each combination is 200,000 B/D when repairs are completed. The time for a given combination to achieve partial production capacity can be determined by locating the pertinent point along the appropriate curve.

Figures F.3 and F.5 are the key figures for the 1-hr shutdown time; Figs. F.6 and F.7, for the 3-hr shutdown time; Figs. F.8 and F.9, for the 6-hr shutdown time. These six figures are for the case when no decontamination has been performed before repairs.

Figure F.10 is for the case when decontamination has been performed before repairs for a 1-hr shutdown time; the plots have been made from values obtained by adding man-days for decontamination to curves in Fig. F.3 for three combinations of refineries. Figure F.10 is included here to show that the conclusions reached for the case of no decontamination are equally applicable to the case when decontamination is performed. These conclusions are presented below.

F.2 DISCUSSION OF RESULTS

Inspection of Fig. F.3 shows that, for 100% recovery, one refinery capable of processing 200,000 B/D of crude requires about 70,000 man-days for repairs, whereas twenty 10,000 B/D refineries require about 4200 man-days. In other words, the larger refinery requires an average of 0.35 man-days per barrel per day to achieve 100% production capacity, whereas each refinery of the smaller group requires only 0.021 man-days per B/D. Thus, for a larger refinery the repair effort (man-days) per unit return of production capacity is significantly greater than that for a smaller refinery. For cases of partial recovery, similar conclusions are reached.

From Fig. F.5, comparisons can be made of the days required to complete repairs. One large 200,000 B/D refinery with the work force noted would require 100 days for 100% repairs. The combination of twenty 10,000 B/D refineries would require 9 days. (For the large refinery, the repair work force is estimated to be about 2200 persons; for the twenty 10,000 B/D refineries combined about 1400 persons.) The conclusion here is that, for a 1-hr shutdown time, to achieve the same percentage of production capacity would take less time for a small refinery than a large refinery. Similar conclusions can be reached for the 3-hr and 6-hr shutdown times, and the order of magnitude of relative repair effort and time can be similarly determined.

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Fig. F.5 Repair Time vs Total Production Capacity for Various
Refinery Combinations and 1-Hr Shutdown Time

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Fig. F.6   Repair Effort vs Total Production Capacity for Various
Refinery Combinations and 3-Hr Shutdown Time

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The figure is a log-log plot. The vertical axis is labeled REPAIR TIME (DAYS) ranging from 1.0 to 10^2. The horizontal axis is labeled TOTAL CAPACITY (B/D) ranging from 10^4 to 10^6, with an inner scale labeled PERCENT OF NORMAL PRODUCTION CAPACITY (10, 20, 30, 50, 100).

Text within the plot:

Repair crews consist of 75% of total number of employees (Figure F.4) working three 8-hr shifts per day.

Each curve represents a total capacity of 200,000 B/D.

Curve labels:
ONE - 200,000 B/D REFINERY
TWO - 100,000 B/D REFINERIES
FOUR - 50,000 B/D REFINERIES
TEN - 20,000 B/D REFINERIES
TWENTY - 10,000 B/D REFINERIES

Fig. F.7   Repair Time vs Total Production Capacity for Various
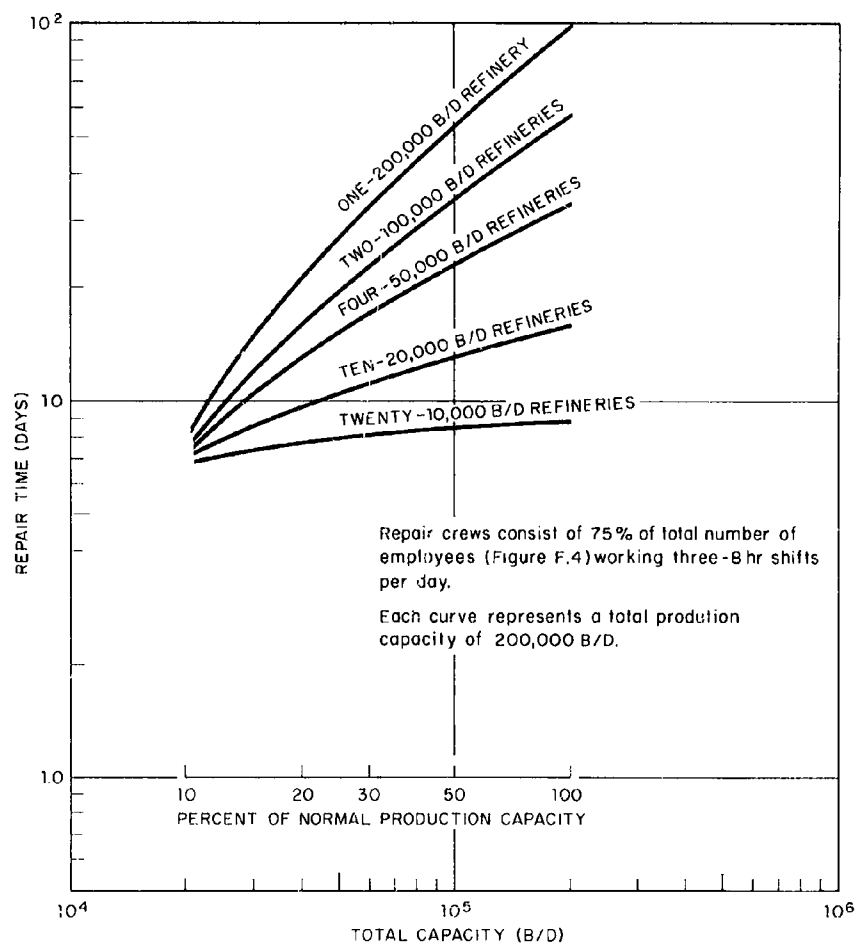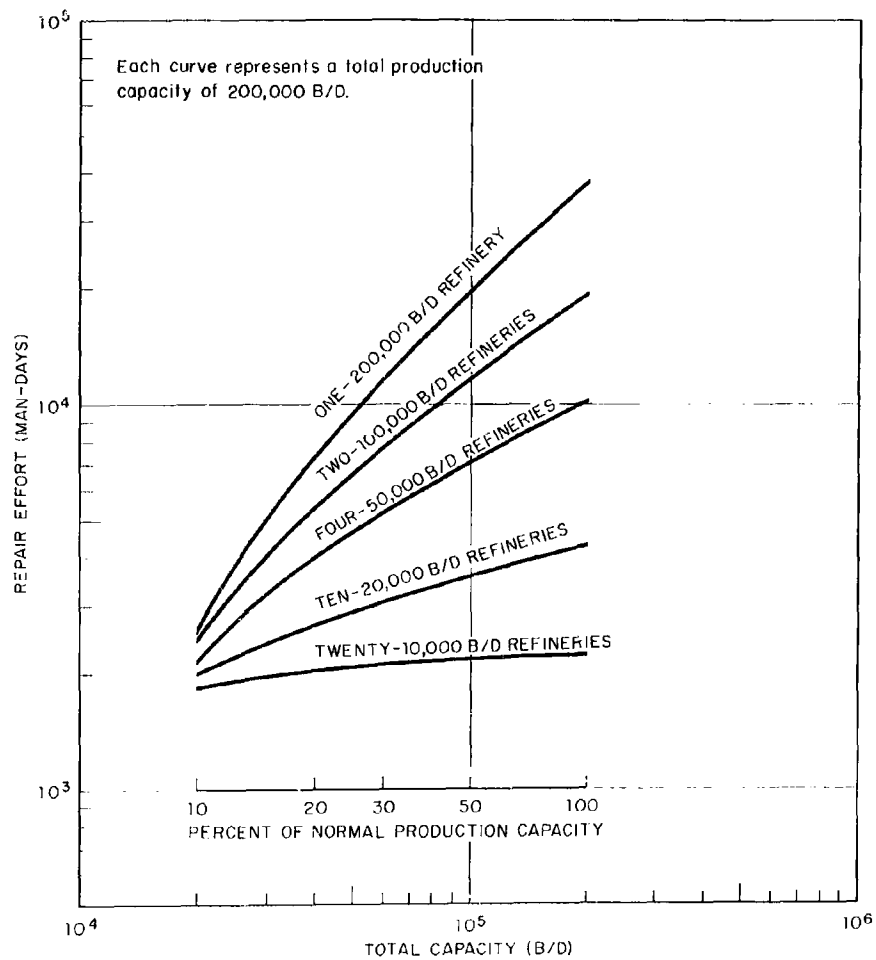Refinery Combinations and 3-Hr Shutdown Time

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Fig. F.8 Repair Effort vs Total Production Capacity for Various
Refinery Combinations and 6-Hr Shutdown Time
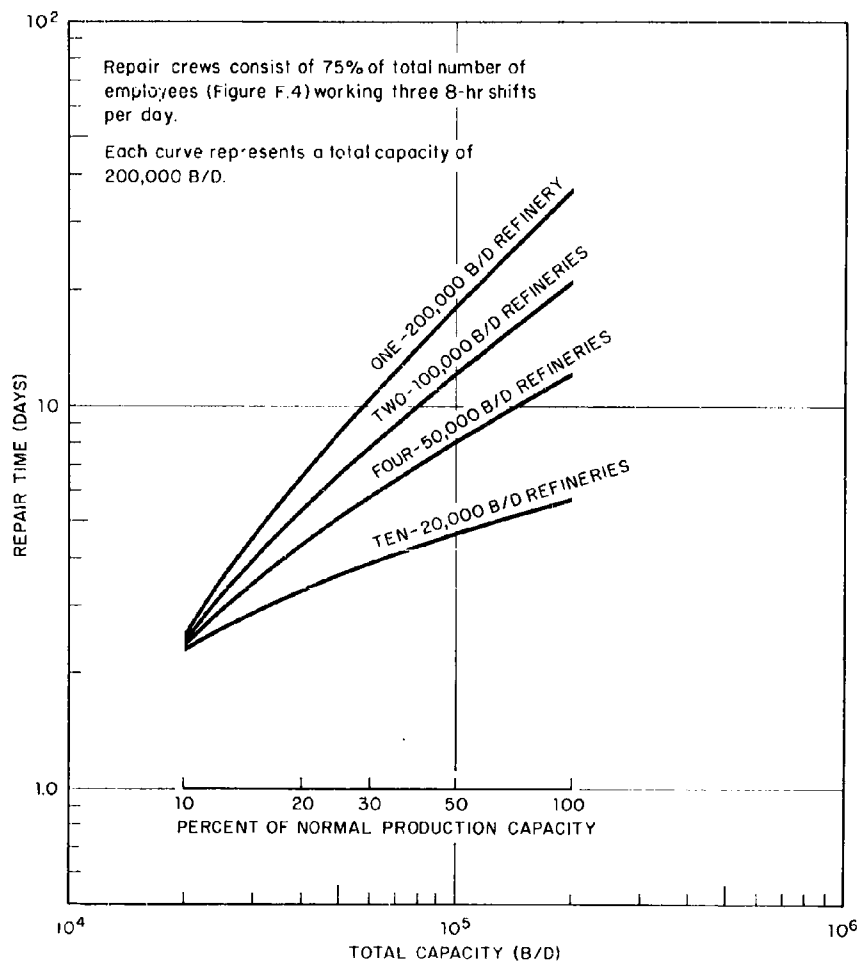
Fig. F.9 Repair Time vs Total Production Capacity for Various
Refinery Combinations and 6-Hr Shutdown Time
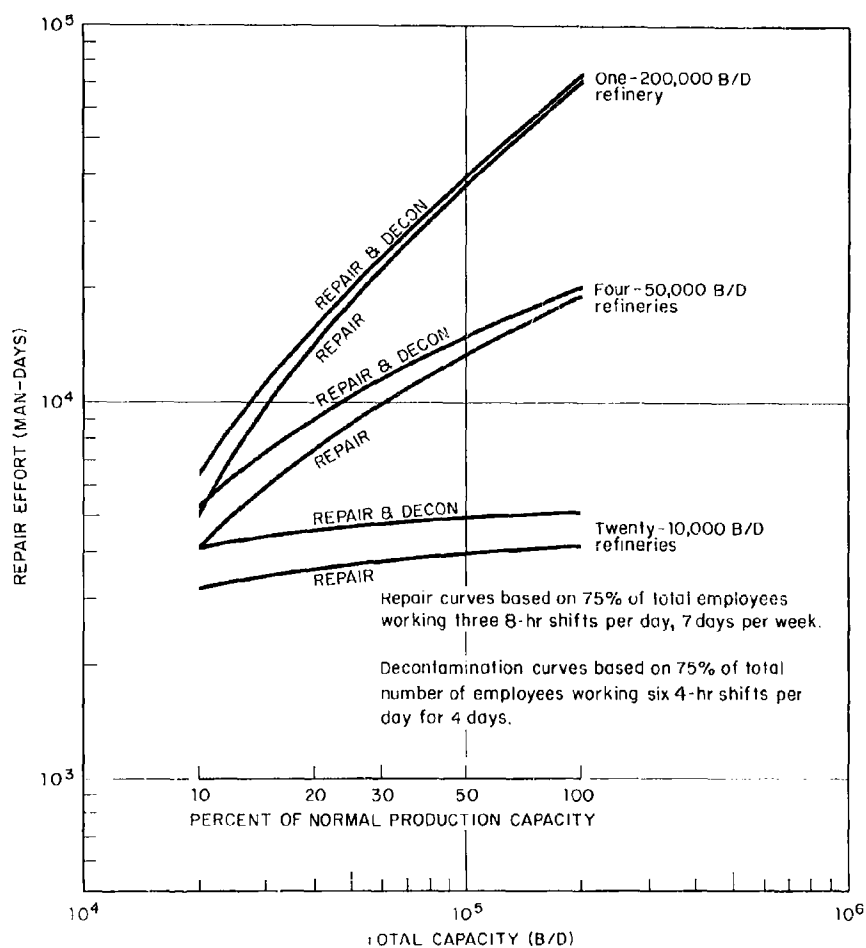
Fig. F.10 Relative Effort for Decontamination and Repair for
Various Refinery Combinations and a 1-Hr Shutdown Time

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It may be pointed out that these same conclusions had been reached qualitatively by the authors, before receipt of the questionnaire, when refinery personnel explained what damage would be caused in various-sized plants by emergency shutdown. However, it was not realized that the differences in effort and time required for large and small refineries would be as great as the results of this analysis lead one to believe.

F.3 CONCLUSIONS AND RECOMMENDATIONS

1. Large refineries are much more vulnerable to fast emergency shutdown than smaller refineries are.

2. In case of expected nuclear attack with the possibility of fallout contamination of refineries, it may be advisable to consider shutting down large refineries in advance of the attack and letting the smaller refineries continue operation if a choice is needed and possible.

3. If a group of various-sized refineries are damaged by fast shutdowns and if their shutdown times are known to be about the same, recovery of the smaller refineries should be performed first--all other factors being equal.

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Horn 24 June 1963 156 p. tables illus. 18 refs.
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1. Refineries.
2. Countermeasures.
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that will eventually be fed to automatic computers to prepare production programs,
consistent with surviving resources, for meeting priority requirements during the
first two years after attack. The present study deals with the petroleum refinery
industry. The case studied is that in which a given refinery is contaminated by
radioactive fallout from one or more nuclear detonations occurring essentially
simultaneously at some distance so that the refinery is not damaged directly by
blast or fire. However, the plant will suffer severe physical damage from insuf-
ficient time to shut down the equipment. Recovery will then consist of a waiting
period to allow the radioactivity to decay, a decontamination period, and an
equipment repair period. Estimates of the recovery times and efforts are made
for various choices of the controlling parameters - length of work shift; standard
intensities, etc; these estimates are applicable to refineries of various sizes. Re-
commendations are made that would reduce the effects of such attacks in oil
refineries and expedite their recovery.
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RECOVERY OF PETROLEUM REFINERIES CONTAM-
INATED BY FALLOUT by L. Minvielle and W. Van
Horn 24 June 1963 156 p. tables illus. 18 refs.
UNCLASSIFIED

The Office of Civil Defense, Department of
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covery of certain essential major in-
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of nuclear attack. Various agencies
are developing recovery input data
(over)

1. Refineries.
2. Countermeasures.
3. Radioactive fallout.
4. Nuclear explosions.

I. Minvielle, L.
II. Van Horn, W.
III. Title.

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that will eventually be fed to automatic computers to prepare production programs,
consistent with surviving resources, for meeting priority requirements during the
first two years after attack. The present study deals with the petroleum refinery
industry. The case studied is that in which a given refinery is contaminated by
radioactive fallout from one or more nuclear detonations occurring essentially
simultaneously at some distance so that the refinery is not damaged directly by
blast or fire. However, the plant will suffer severe physical damage from insuf-
ficient time to shut down the equipment. Recovery will then consist of a waiting
period to allow the radioactivity to decay, a decontamination period, and an
equipment repair period. Estimates of the recovery times and efforts are made
for various choices of the controlling parameters - length of work shift; standard
intensities, etc; these estimates are applicable to refineries of various sizes. Re-
commendations are made that would reduce the effects of such attacks in oil
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